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Characterization of groundnut shell ash as partial replacement of cement for cheaper construction in north-western Nigeria

Umar Abdulrahman[1*] and Uwaisu A. Ali[2]

[1]Department of Chemistry, Shehu Shagari College of Education, Sokoto
[2]Department of Physics, Shehu Shagari College of Education, Sokoto

*Corresponding author's email: aumar5k5@gmail.com

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Groundnut is an important cash crop produced in large quantity in North-Western Nigeria. The production of ground nut reached its peak in Nigeria during the period of 1969 to 1980s, when approximately 1.7 million tonnes of the pods were produced from an area of 1.9 million hectares. This enormous waste is presently not being harnessed productively in other than burning, which is a major air pollution and indiscriminate dumping that cause environmental hazard. Groundnut husk when burnt under controlled temperature has been found to be rich in silica. The benefit of high silica content makes it very useful pozzolanic material and a good possible admixture in concrete production. Conversion of wastes to wealth is the new vogue all over the world; this is not only to reduce environmental degradation and pollution but also to effectively put these wastes into use that would be beneficial to mankind. This paper investigated the suitability and application of Groundnut Shell Ash (GSA) from Sokoto, Kebbi and Zamfara states as pozzolanic and siliceous partial mineral admixture in cement production for cheaper, improved strength and durability of mortar and concrete making in North-Western Nigeria. Six sandcrete blocks using groundnut shell ash (GSA) as partial cement admixture were investigated for each replacement levels of cement to GSA ration of 100/0%, 90/10%, 80/20%, 70/30%, 60/40%, and 50/50% with groundnut shell ash. The results indicated that the strength of the sandcrete decreases with increase of cement above 20% replacement.

Keywords: Groundnut Shell Ash, Sandcrete blocks, Compressive Strength test

1. Introduction

Majority of the building components in the tropic region of Northwestern Nigeria are made from cement, water and sand moulded into different sizes and shapes. Studies on the quality of sandcrete blocks have been conducted in many parts of the world. Some have shown the non-uniformity in their quality (Salman, 2021). Others have shown the effect of admixtures on the strength of the blocks (Afolayan, et al, 2008: Abubakar and Omotoriogun, 2022).

Groundnut is found in both the urban and rural areas of Nigeria. Groundnut shell is produced widely as a waste material after milling. The shell occupies 20–24% of the rough groundnut harvested, although the ratio differs by variety, (Usman et al, 2019). About 58 tons of groundnut shell are generated annually in the world (Sani, et al, 2023). Its application in some parts of human life will enhance sustainability of the environment and economic development especially in the developing countries like Nigeria. The current high cost of cement, used as binder, in the production of mortar, sandcrete blocks, and concrete has necessitated the search for alternative materials with cementitious properties. In addition to cost, high energy demand and emission of CO_2, which is responsible for global warming, the depletion of limestone deposits associated with cement production is causing environmental degradation in some parts of northwestern states of Nigeria like Sokoto, Kebbi and Zamfara States. Research on alternative to cement, has so far centered on the partial replacement of cement with different materials. In advanced countries, partial replacement of cement with pozzolans is well documented and recommended, (Reddy, et al, 2017). Pozzolans as defined by Anosike and Oyebade, (2012). are siliceous materials, which by itself possesses no cementitious properties but in processed form and finely divided form, react in the presence of water with lime, to form compounds of low solubility having cementitious properties. They are grouped into natural and artificial sources; clay and shale calcined to become active, volcanic tuff and pumicite are naturally occurring pozzolans, whereas good blast furnace slag and fly ash are the artificial sources; clay and shale calcined to become active, volcanic tuff and pumicite are naturally occurring pozzolans, whereas good blast furnace slag and fly ash are the artificial varieties (Ranatunga, et al, 2023).

In advanced countries, the use of fly ash, a residue obtained from the combustion of pulverized coal in partial replacement of cement is recommended within the range of 10-30% by weight of cement. In Nigeria, Ozoani and Onwudiwe (2023) recommended substitution of cement with groundnut shell ash in sandcrete not exceeding 10%. Mixtures of Portland cement and pozzolanic material is referred to as pozzolanic cements, such cement have the following advantages good resistance to chemical attack, low evolution of heat of hydration, economy, improvement of workability, reduction of bleeding and greater impermeability. Its disadvantages include, slower rate of strength development and increased shrinkage (Agbede and Obam, 2008). In the third world countries, the most common and readily available material that can be used to partially replace cement without economic implications are agro based wastes, notable ones are Acha husk ash (AHA), Bambara groundnut shell ash (BGSA), Bone powder ash (BPA), Groundnut shell ash (GSA), Rice husk ash (RHA) and Wood Ash (WA). Additionally, agro waste materials include Ashes from the burning of dried banana leaves, bagasse, bamboo leaves, some timber species, sawdust and Periwinkle Shell Ash (PSA) (Odeyemi, et al 2023).

Some of the advantages for using agro-waste residues in the partial replacement of cement include; low capital cost per tonne production compared to cement, promotion of waste management at little cost, reduced pollution by these waste and increased the economy base of farmers when such waste is sold, thereby encouraging more production, conservation of limestone deposits and a reduction in CO_2 emission (Ogork et al, 2015).

2. Materials and Methods

2.1 Material/Sampling

The Groundnut shell was obtained from Yauri in Kebbi north-western Nigeria after threshing/separating the shell from the nut using the threshing machine.

2.2 Methodology

The laboratory analyses were carried out at the quality control BUA Cement PLC Sokoto, Ahmadu Bello University Multipurpose Science Laboratory, Zaria, Chemistry and Physics Laboratory of Shehu Shagari College of Education, Sokoto. 20 Samples of 10kg of the shells from Yauri locality were sampled and burn under a controlled atmosphere in a muffle furnace at a temperature of 550^{o}C for about one hour to preserve the amorphous form of the ash, as described by Oyedepo et al, (2015) and Salman (2021). The fully burnt groundnut shell ash was the grind and sieved to ensure proper fineness of the ash. The burnt ash was then sieved through British Standard sieve of 75 microns after grinding. The portion passing the sieve was recorded to the required degree of fineness that is 63 microns while the ash to be retained on the sieve was reground and sieve again according to the methods of Odeyemi, et al, (2023).

The analysis of the groundnut shell ash was carried out by x-ray fluorescence analysis using fused bead XRF VFD45000. Silt content and particle size distribution was carried out on the sand sample to ensure its suitability for block making in accordance to BS8110 (1985) and adopted by Odeyemi, et al, (2023). The mix ratio adopted was one part of binder to eight parts of sand (1:8) at 0%,10%,20%,30%,40%, and 50% replacement levels of cement with the groundnut shell ash. 100 concrete cubes of 50mm×50mm ×50mm were casted in accordance with ASTM C618. The specimens were cured in curing tank containing clean water at a temperature of 18°C to 22°C. The compressive strength test of the GSA sandcrete blocks were performed in accordance with ASTM C618 and adopted by MayRoose, et al, (2022). The blocks were casted for replacement levels of 0%, 2%, 4%,6%,8%, and 10% and cured for 7 days, 14 days, 21 days and 28 days respectively. For each mix, 3 cubes were crushed to obtained the average strength. Specific gravity, silt content and slump tests were conducted. Sokoto Cement brand of ordinary Portland cement was used in this research. The sprinkling method of curing was adopted in accordance with NIS (2000) and the compressive strengths of the blocks was tested in accordance to ASTM (1992) as adopted by Ghosal and Moulik, (2015): Gadanayak and Giri, (2023).

3. Results and Discussion

3.1 Chemical Analysis of Groundnut Shell Ash (GSA)

Table 3.1 shows chemical composition of the GSA. Most samples were found to have parameters within that of the ordinary Portland cement. However, that of Potassium Oxide(K_2O) and Phosphorus Oxide (P_2O_5) exceeded the maximum values for cement while Calcium Oxide

(CaO) was below the minimum value for cement as observed by Buari, (2013).

Table 3.1: Results of X-Ray Fluorescence of GSA compared to Cement

PARAMETERS	GSA (%)	CEMENT (%)
SiO_2	24.36	17-25
Al_2O_3	5.75	3-8
Fe_2O_3	2.16	0.5-0.6
CaO	10.91	60-67
MgO	4.72	1-6
SO_3	6.40	1-2
K_2O	16.8	0.1-3
Na_2O	2.30	01-3
P_2O_5	2.0	0.1-0.5
MnO_2	0.29	0.1-3
TiO_2	0.82	0.1-1
LOI	23.05	17-25

3.2. Specific Gravity of the GSA

The specific gravity of the Groundnut Shell Ash (GSA) in this study was fond to be 2.30 and 2.67 for the sand used as shown in table 3.2. Abubakar and Omotoriogun, (2022). found that the specific gravity ranges from 1.9 to 2.4 for ash and 2.6 to 2.7 for natural aggregates. This has shown that both the GSA and sand for this study are within this range. Specific gravity of the ash is a function of its weight, thus since the specific gravity of the ash is less than the weight of the cement (specific gravity of 3.15), the composite sandcrete block was observed to be lesser in weight than that of the cement as reported by Ikumapayi, (2018)..

Table 3.2: Result of specific gravity of Groundnut shell ash and Sand

Sample	Specific Gravity	Silt Content (%)
Groundnut shell ash	2.30	0.00
Sand	2.67	3.68

3.3 Silt Content

Alutu and Omorogie, (2009): Kumar and Lalotra, (2023) reported that, silt content within the rage of 3% to 8% for sand is within the acceptable limit. The silt content of the sand used for this study was 3.7% as presented in table 3.2, this shows that the sand is suitable for sandcrete block.

3.4 The Slump Test of the GSA

Table 3.3 shows the result of water to binder ration with percentage replacement of cement with groundnut shell ash, where it indicates that groundnut shell ash mixture content required more quantity of water than cement to attained same workability status as that of the cement. This shows the groundnut shell ash has greater adsorption ability than the cement which could be due to high carbon content as reported by Akanbi et al, (2022): Odeyemi, et al, (2023).

Table 3.3: Result of Water/binder ratio with %replacement of cement with GSA

%Groundnut Shell Ash	0	10	20	30	40	50
Water/Binder ratio	0.51	0.47	0.49	0.53	0.55	0.56
Slump (mm)	15	30	25	20	25	20

3.5 Setting Time of GSA Replacement

Table 3.4 shows the result of percentage admixture replacement of ordinary cement with groundnut shell ash and their setting time. The results indicate a slower pattern in the initial and final setting times of the sandcrete blocks under study with increase of groundnut shell ash in the content of the mixture. Alutu and Omorogie, (2009): Lakshmi, (2017) reported that the exothermic reaction involved in the hydration of cement generates heat which contributes to the faster setting of the blocks. Thus, the addition of GSA may have decreased the heat generation, this may be responsible for the delay in the hardening of the paste. This is corroborated with the case of zero (0%) addition of GSA where the initial and final setting times was found to be 94 and 147 minutes respectively, but at 50% replacement, the initial and final setting times was 566 and 911 respectively. Generally, increasing setting times was observed with increasing percentages of groundnut shell as replacement of cement.

Table 3.4: Variation of setting time with increasing GSA replacement

GSA Replacement (%)	0	10	20	30	40	50
Initial Setting Time (m)	94	179	192	298	377	566
Final Setting Time (m)	147	356	516	689	762	911

3.6 Compressive Strength of the GSA

The results of compressive strengths of the groundnut shell ash replacement as shown in table 3.5 indicates that gradual increase in strength was observed with curing age up to the 28 days at lower percentages of the replacement of cement with the GSA. Then a gradual decrease in strength was recorded with increasing percentages of the groundnut shell ash in the sandcrete block mixture especially at 40% and 50% GSA replacement ratios as reported by Adajar, (2020): Lakshmi (2017): Lakshmi, et al, (2017): Oyedepo, et al, (2015).

Compressive strength values recorded for 0%, 10%, 20% and 30% replacement at 28th day curing were 4.62 N/mm^2, 3.97 N/mm^2, 3.60 N/mm^2 and 3.11 N/mm^2 respectively where 20% replacement was found to have the maximum compressive strength. Abdurrahman, et al, (2022): Lakshmi, (2017) reported that cement blended with pozzolans would produce 65% to 95% strength of the ordinary Portland cement concrete in 28 days. Furthermore, they reported that their strength normally improves with age since pozzolans react slowly than cement due to different composition and at one year about the same strength will be obtained.

Table 3.5: Result of Compressive strength test of the GSA blocks

GSA Replacement (%)	Curing Age (Days)	Average Crushing Load (KN)	Compressive Strength (N/mm^2)
0	7	52	1.42
	14	84	2.47
	21	130	3.55
	28	161	4.62
10	7	42	1.32
	14	82	2.33
	21	121	3.12
	28	145	3.97
20	7	38	1.21
	14	72	2.32
	21	96	2.78
	28	131	3.60
30	7	27	0.92
	14	46	1.56
	21	65	1.71
	28	89	3.11
40	7	13	0.37
	14	26	0.72
	21	38	1.21
	28	42	1.22
50	7	8	0.36
	14	15	0.51
	21	19	0.33
	28	24	0.67

4. Conclusion

The following conclusions were derived from the findings of the study:

1. Partial replacement of cement with Groundnut Shell Ash (GSA) in block making is possible and sustainable
2. That satisfactory compressive strength of up to 20% replacement of cement with groundnut shell ash can be achieved
3. The Compressive strength decreases with increasing groundnut shell ash as cement replacement beyond 20%
4. The setting time of the sandcrete blocks increases with increasing groundnut shell ash content
5. Water requirement for workability increases with increasing replacement of cement with groundnut shell ash
6. Generally, Groundnut shell Ash (GSA) can serve as partial cement replacement (up to 20%), this can help manufacturers of block to make the desired profit in utilizing this waste material without compromising the standard.

5. Recommendations

Based on the research findings, the following recommendations were made:

1. Further research and testing should be conducted to explore the long-term performance and durability of GSA-based cement mixtures in different environmental conditions.
2. Awareness campaigns and capacity-building initiatives should be organized to disseminate the benefits of GSA utilization and encourage its adoption in the construction industry.
3. Regulatory bodies and policymakers should consider incorporating guidelines and incentives to promote the use of GSA as a sustainable and cost-effective construction material and as a tool of environmental waste management.

Conflict of Interest

The author declares that there is no conflict of interest.

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