EFFECT OF GROUNDNUT HUSK ASH AND SILICA FUME ON PROPERTIES OF MORTAR

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ABSTRACT

Effects of ground nut shell ash and silica fume on properties of cement mortar, central composite method (CCD) was utilized to design the experimental data. Two input factors (GSA 10-20%) and (SF 5-10%) and two responses (consistency and setting time) were considered in the design. A total of 13 experimental runs were generated and tested. The results show that Both Groundnut husk ash and silica fume increase water requirement but GHA increase more than silica fume for consistency, while for setting time result show that Groundnut husk ash and silica fume delayed setting time, however GHA significantly delayed the setting time than silica.

KEY WORDS*: Groundnut shell, silica fume, properties of mortar, central composite design, experimental data, setting time, consistency.*

I. INTRODUCTION

Cement production is one of the major contributors to carbon dioxide (CO_2) emissions. It is responsible for 8% of the global artificial CO_2 emission. More than 4 billion metric tons of cement are produced. China and India are the major cement producers, covering almost two-thirds of cement production worldwide. For the fabrication of every ton of cement, around 900 kg of CO_2 is emitted. The high level of CO_2 emission happens when burning fossil fuels to generate heat to initiate the cement manufacturing process and thermal decomposition of calcium carbonate in the progression of manufacturing cement clinker. During this process, 30–40% is derived from burning fuels and 60–70% result from decarbonation. Although cement production contributes to a significant amount of CO_2 emission, it still remains an inevitable constituent in most of the construction materials such as concrete, cement mortar, etc. Since reducing the embodied energy and CO_2 emission trading are of enormous importance to control global warming in the future, the construction industry faces growing pressure to find alternative supplementary cementitious materials to replace cement in construction. The construction materials already incorporate a broad range of supplementary cementitious materials such as fly ash, silica fume, limestone, metakaolin, granulated blast furnace slag and volcanic pozzolanas. [1]

Pozzolans are materials that consist mainly of silica and alumina and are able to combine with $Ca(OH)_2$ in the presence of water to produce new reaction products that possess strength binding characteristics. Pozzolans are widely acceptable because of the various benefits they offer to concrete or mortar produced when ordinary Portland cements (OPC) is partially replaced with them. They offer beneficial effects like increased compressive strength and flexural strengths, and better durability at later age; some also improve workability, lower heat of hydration and increase resistance to both sulphate and alkali-silica reactions. These factors in addition to the economic and ecological advantages of pozzolans over OPC, make them beneficial for use in large concrete projects such as bridges and dams. [2].

Groundnut shell, a by-product of groundnut production, is one such agricultural waste. The global output of groundnuts in 2020 was around 47 million metric tons. About 21–29% of the weight of the groundnut is made up of groundnut shell. Therefore, the groundnut business produces waste groundnut shells in the amount of 11 million metric tons annually. Although a considerable quantity of groundnut shells is used as biomass for energy, still larger quantity of groundnut shells is being thrown out as waste. The origin of the groundnut and processing conditions significantly change the chemical composition of groundnut shell ash (GSA), still, silica is the main content found in GSA and it varies between 16 and 51%. The presence of reactive silica can react chemically with calcium hydroxide and generate calcium silicate hydrate (C-S-H). So, it has the potential to be used as a supplementary cementitious material in construction. when more cement is substituted with GSA, the water requirement for a uniform mix increase. Previous research has also revealed that using a higher amount of GSA as a cement substitute decreases density. The literature reveals two different trends related to the compressive strength of concrete and cement mortar. Firstly, the compressive strength increases up to an ideal level of GSA as cement replacement and then decreases. Secondly, compressive strength decreases when GSA is used as a cement substitute in concrete and cement mortar, at a replacement level between 10 and 15%. [3].

SF is a by-product from the silicon and Ferro-silicon alloy industries . Quartz is heated by wood chips, coal, or coke in an electric furnace with a high temperature of 2000 ˚C to reduce oxygen content. The fume condenses and oxidizes at the top of the furnace to form silicon oxide (SiO_2), having ultrafine particle size, and comprising about 75% SiO_2. The quality of silica fume is associated with the quantity of silica content . The use of SF in the concrete increases the water requirement because of its ultra-fineness; consequently, it’s essential to add super-plasticizer to attain the required workability. The high pozzolanic reactivity in SF positively affects the increased compressive strength, lime-consuming activity, small pore size distribution, and lower heat release . it is reported that an increase of 9.4%, 30.76%, and 34% in the compressive strength for the concrete containing 10%, 15%, and 20% of SF, respectively. SF is most extensively used as a pozzolanic material in the UHPC production because of enhancing the packing density due to the filling effect and production of extra calcium silicate hydrate (C–S–H) gels. The incorporation of SF had an influence on the energy absorption capacity of UHPC during the pull-out process. investigation show that the effect of SF on the fracture and mechanical properties of HPC, with different replacement levels of SF. The results revealed that the SF improved the performance of HPC and recommended the use of further SF content as a cement replacement. [4].

The recommended proportion of silica fume replacement to achieve the strongest possible concrete after 28 days is between 5% and 15%. This improvement is attributed to the pozzolanic property of silica fume, which reacts with calcium hydroxide produced during cement hydration to form calcium silicate hydrate (C-S-H) gel, enhancing the mechanical properties of the concrete. To promote sustainability, cement should be replaced with more environmentally friendly materials that still possess strong binding properties. Pozzolanic materials such as silica fume, fly ash, and metakaolin can serve as partial substitutes for cement in concrete. It has been demonstrated that there is significant benefits of incorporating pozzolanic materials, including improvements in workability, mechanical strength, and aggregate interlocking when silica fume is used as a partial cement replacement.[5]

II. MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1 Cement

The cement used in this research is ordinary Portland cement Dangote brand cement which was obtained in Nigeria and conforms with the specification of BS 12:1991. Table 1 shows the oxide composition of the cement.

Table 1. Oxide Composition of Dangote Brand OPC

Oxide	Dangote OPC (%)	Standard OPC (%)
SiO_2	21.55	17-25
Al_2O_3	5.28	3-8
SO_3	1.5	2.0-3.5
CaO	64.45	60-67
Fe_2O_3	3.95	0.5-0.6
LOI	1.44	0.3-1.2

3.1.2 Groundnut Husk Ash

Groundnut husk was sourced from Katsina State, Nigeria. The Groundnut Husk Ash (GHA) was obtained by a two-step burning method, where the groundnut husk was burnt to ash and further heating the ash to a temperature of about 600°C in a kiln and controlling the firing at that temperature for about two hours and the ash was allowed to cool before sieving through a 75 µm sieve. The fully burnt groundnut shell ash was then grind and sieved to ensure proper fineness of the ash. To improve its reactivity, the ash was ground to finer particles after heating.

3.1.3 Test for Chemical Composition of GHA

The X-ray fluorescence test which is carried out to determine the percentage of cementitious elements present in the GHA. The facility for performing this test was not available in our lab so it was tested at private laboratory at Kaduna.

Figure 1 - Griundnut Husk Ash

3.1.4 Fineness Test On GHA

Procedure;

The test was conducted in accordance with ASTM C311. The procedure involved weighing 100 grams of GHA and placing it on a 40-µm sieve. Pressurized tap water was applied to the sieve containing the sample, and the washing process continued until the water passing through the sieve was as clear as the tap water. The agitated sample was then allowed to settle, after which the water was decanted, and the settled sample was oven-dried at a temperature of 105°C.

After 24 hours, the sample was removed from the oven and weighed. The fineness of the GHA was calculated using Equation 1.

$$\text{Fineness} = M2 / M1 \times 100 \quad (1)$$

Where M1 represents the mass of GHA before sieving, and M2 is the mass of GHA retained on the sieve after wet sieving.

Figure 2 - Determination of GHA Fineness by fineness test

3.1.5 Strength Activity Index Test On GHA

Fine Sand (Used in the test)

Natural sand with small particle sizes was used as a fine aggregate. The sand was sourced from the ABU Dams. Based on the grading requirements for ASTM C33, the sand is suitable for used in concrete/structural mortar. It was kept in saturated surface dry condition prior to sieving and use in the laboratory. The sieve analysis carried out is in conformance with BS EN 993-1 (1997).

Figure 3 - Fine sand

Test Procedure:

The strength activity index (SAI) test on GHA was conducted to determine its reactivity in accordance with ASTM C618. Manual mixing and compaction were adopted for this experiment. The procedure involved measuring the required quantities of cement, sand, and water as recommended by ASTM for the control sample mix. Similarly, the required amounts of cement, sand, GHA, and water were measured for the blended sample following ASTM C618. Each sample was dry-mixed individually before gradually adding water. Water was added bit by bit, and the mix was transferred to a flow table to ensure the required flow was achieved, as specified by ASTM C618.

The resulting cement mortar for both the control and blended samples was cast into molds of size 50 mm × 50 mm × 50 mm and labeled appropriately. The casted mortar samples were covered with polyethylene sheets for 24 hours. After 24 hours, the samples were demolded and cured in water for 7 and 28 days. Upon completing the curing period, the samples were crushed, and their individual compressive strengths were recorded. The strength activity index (SAI) was calculated using Equation 2.

$$\text{Strength activity index} = (SB / SC) \times 100 \qquad (2)$$

Where SB is the compressive strength of the blended sample at 7 or 28 days, and SC is the compressive strength of the control sample at 7 or 28 days.

3.1.6 Silica Fume

Densified silica fume is use for the study, and its obtained from the supplier.

Figure 4 - Silica Fume

Table 2. Chemical Properties of Silica Fume

Oxide	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**CaO**	**Na_2O**	**Na_2O**
Constituents (%)	94	0.6	0.4	0.8	0.35	0.4	0.3

3.1.7 Water

Clean tap water that fit for drinking was used for the entire work is a Pipe-borne water pumped at the Ahmadu Bello University. The quality of water is in conformance with BS 3148 (1980), which specifies that water to be used for concrete must be safe for drinking, free from odor, color taste and impurities.

3.2 Methodology

3.2.1 Preparation of Samples

Nine different paste mixes constituting GHA and silica fume in different proportions were produced. The mix proportions are shown in Table 3. The mix without GHA and silica fume (100% cement) serve as control.

Table 3. Mix Proportion Use for Consistency and Setting Time

Mix	% of Cement	% of silica fume	% of GHA	ST (min)
Control Mix	100%	0	0	70
1	88.2	10	1.8	100
2	90	5	5	140
3	80	15	5	160
4	84.6	2.9	12.5	200
5	77.5	10	12.5	210
6	75	5	20	240
7	66.89	10	20	250
8	65	15	20	260
9	70.5	17	12.5	270

3.2.2 Consistency Test

The consistency test was carried out to examine the water requirement for the mix using the procedure stipulated by Indian standard IS: 4031 (Part 4) 1988.

Procedures: -

The standard consistency test was determine using the Vicat apparatus, 400 g of cement was weighed and placed in an enameled tray. Approximately 25% water by weight of the cement (about 100 mL) was added and mixed thoroughly to form a uniform paste. The mixing process, referred to as "gauging time," did not exceed 3 to 5 minutes. Next, the Vicat mould was placed on a glass plate and filled completely with the prepared cement paste. The surface of the paste was smoothed and leveled to align with the top of the mould. The entire assembly, including the mould, cement paste, and glass plate, was then positioned under the Vicat apparatus rod equipped with a plunger. The plunger was lowered gently until it touched the surface of the cement paste and then released quickly to allow it to penetrate the paste under its own weight. Finally, the depth of penetration was measured and recorded. The standard consistency was obtained when the plunger penetrates within 5-7mm on the plunger reading scale. The same process was repeated for the 9 samples.

Figure 5 - Determination of Consistency

3.2.3 Setting Time Test

The setting time test was carried out to examine the time at which paste start losing its plasticity to the time which completely losses its plasticity. The test was conducted based on procedure describe in BS 12 standard.

Procedure:

After the consistency was achieved, the cement paste was transferred to the initial setting time apparatus to measure the initial and final setting times. This was done using the amount of water and cement corresponding to the standard consistency.

A 1 mm diameter needle was used, and the plunger was released freely to penetrate the cement paste. The depth of penetration was read on the Vicat ruler scale. The needle was allowed to penetrate the sample by the free fall of the plunger. Trials were conducted at 15-minute intervals until the depth of penetration reached 5 mm. The elapsed time from adding water to dry cement up to this point was recorded as the initial setting time.

The initial setting time needle was then replaced with the final setting time needle, which had an angular cutting edge. The final setting needle was allowed to penetrate the sample every 15 minutes until the needle only made an impression on the paste surface, but the cutting edge failed to penetrate.

The initial and final setting time was calculated using the formula in equation 3 and 4

Initial setting time = T2–T1 (3)

Final setting time = T3–T1 (4)

Where,

T1= time at which water is first added to cement

T2=time when needle fails to penetrate 5mm to 7mm from bottom of the mold

T3=time when the needle makes an impression but the attachment fails to do so.

Figure 6 – Determination of Setting time

III. RESULT AND DISCUSSION

4.1 Properties of Groundnut Husk Ash (GHA)

The physical characteristics of Groundnut Husk Ash (GHA) were assessed, revealing that it is sufficiently reactive for use in cementitious applications. The strength activity index (SAI) was evaluated at 7 and 28 days, exceeding the ASTM C311 minimum requirement of 75%. Specifically, the 7-day SAI was 83%, and the 28-day SAI was 88%, confirming its pozzolanic reactivity Table 4, The fineness of GHA was determined by sieving, with 32% of the material retained on a 45 µm sieve, which is within the ASTM C311 requirement of ≤34% (Table 4.2). The chemical compositions of the GHA shown in Table 5. Based on its chemical composition, GSA constitutes silica, calcium oxide and alumina as the major oxides. The summation of silica, iron oxide and alumina is 30.95%, which is less than the minimum of 50% stipulated by the ASTM 618 for Class C pozzolan. However, this suggests that GHA could serve as a suitable pozzolana if calcined at optimized temperatures higher than 600°C. Table 6.

Table 4 Strength Activity Index Test Result

Hydration Period	Strength Activity Index	ASTM C311 Requirement
7days	83	≥75% Minimum
28days	88	≥75% Minimum

Table 5 Fineness Test Result of GHA

Material	%Retained On The Sieve	ASTMC311 Requirement
Groundnut Husk Ash	32	≤34% Maximum

Table 6 Chemical Composition of GHA by X-Ray test

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	ZnO	TiO	MnO
25.98	2.24	2.73	6.77	1.21	0.07	0.33	0.12

4.2 Consistency

The consistency of various mix compositions, shown in Figure 8, indicated that mixtures containing GHA and silica fume required more water to achieve the desired consistency compared to the control mix. The water demand increased with higher proportions of GHA and silica fume, with GHA contributing a higher water requirement. The spongy nature of GHA particles which is typical to most agro-waste ashes, leading to their high surface area may be responsible for the high water requirement.

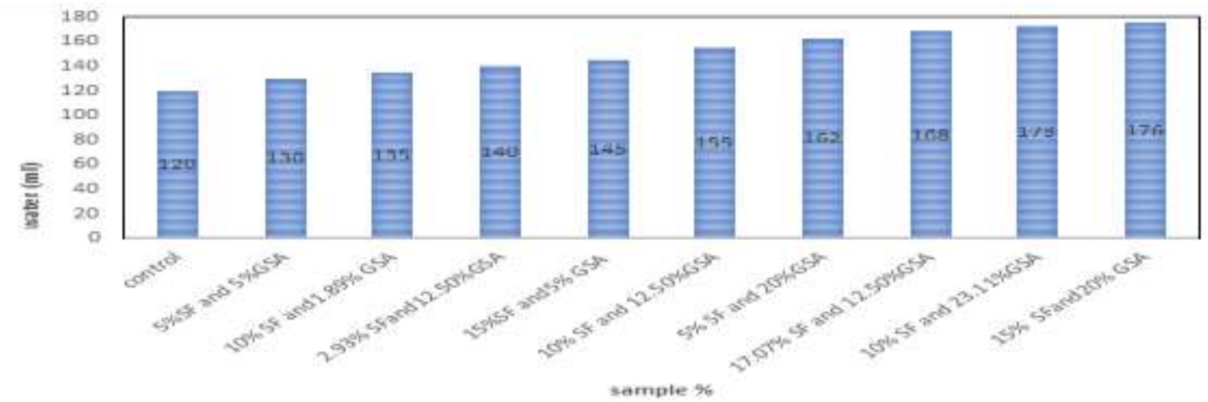

Figure 7 - Consistency of Different Mixes

4.3 Setting Time

The setting times of the different mixes are presented in Table 4.6. Initial setting times varied between 100 and 270 minutes. An increase in GHA content notably delayed the setting time, likely due to the dilution of cement and slower pozzolanic reactions. Silica fume also showed a retardation effect, though it was less pronounced compared to GHA. However, it is noteworthy that at all the replacement levels, the minimum initial setting time (60mins.) and the maximum final setting times (600mins.) recommended by the ASTM standard were not exceeded. This implied that, this combination may be a suitable for use where retardation of setting time is significant.

Table 7 - Setting Time Result

Mix	% of Cement	% of silica fume	% of GHA	ST (min)
Control Mix	100%	0	0	75
1	88.2	10	1.8	100
2	90	5	5	140
3	80	15	5	160
4	84.6	2.9	12.5	200
5	77.5	10	12.5	210
6	75	5	20	240

7	66.89	10	20	250
8	65	15	20	260
9	70.5	17	12.5	270

DISCUSSION

Cement production contributes 7-8% of global CO_2 emissions, with processes like calcination and fossil fuel combustion releasing 0.8–1 ton of CO_2 per ton of cement. In contrast, burning groundnut shells for ash emits only 0.4–0.5 tons of largely biogenic CO_2, as the shells are part of the natural carbon cycle. Using groundnut shell ash (GSA) as a partial cement replacement reduces CO_2 emissions, recycles agricultural waste, and promotes sustainability, significantly lowering the environmental impact compared to cement production.

The use of GHA as a source of SiO_2, Al_2O_3, and Fe_2O_3 is much more cost-effective and sustainable compared to extracting and processing raw materials for cement production. (GHA) has significant advantages over cement due to its high content of SiO_2, Al_2O_3, and Fe_2O_3**,** which enhance its pozzolanic activity. The silica (SiO_2) in GHA reacts with calcium hydroxide during cement hydration to form additional calcium silicate hydrates (C-S-H), improving the strength, durability, and longevity of concrete. The alumina (Al_2O_3) and iron oxide (Fe_2O_3) in GHA further enhance resistance to chemical attacks, thermal stability, and wear.

Additionally, GHA provides economic benefits to farmers by creating a market for groundnut shells, boosting their income and encouraging greater agricultural productivity. It also promotes efficient waste management by converting agricultural byproducts into useful materials, reducing landfill burdens and minimizing soil, air, and groundwater pollution. Its use helps conserve natural resources by reducing the reliance on limestone deposits, ensuring their preservation for future generations. Furthermore, beyond cement replacement, GHA is versatile, finding applications in lightweight concrete, insulation boards, and furniture production, making it an environmentally friendly and practical solution in various industries.

CONCLUSION

The study reveals that both Groundnut Husk Ash (GHA) and Silica Fume (SF) exhibit significant potential as supplementary cementitious materials (SCMs), though their effects on cement properties differ.

- ✓ GHA is a pozzolanic material belonging to class c– pozzolan.
- ✓ Both Groundnut husk ash and silica fume increase water requirement but GHA increase more than silica fume.
- ✓ Both Groundnut husk ash and silica fume delayed setting time, however GHA significantly delayed the setting time than silica.

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