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Assessment of the Short-Term Strength of Groundnut Shell Ash Blended Cement Concrete

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Abstract

The demand rate of cement in the construction industries is affected due to the high cost of cement production leads to the continuous increase in its price in the face of global economic recession. Also, high energy demand and emission of carbondioxide (CO_2) into the atmosphere during cement production, has a negative influence on ecology and future of human beings as a result of global warming. These need to be controlled by sourcing for alternatives for partial replacement of cement. In order to achieve this, an assessment on the characteristic strength performance of Groundnut Shell Ash (GSA) blended with Ordinary Portland Cement (OPC) concrete needed to be carried out. An assessment was done to determine the effect of partially replaced OPC with GSA on concrete workability. The chemical and physical properties of GSA were also considered. Concrete was cast in 72 cubes, 72 cylinders and 72 beams using GSA as partial replacement for cement in different percentages (5, 10, 15, 20 and 25), and subsequently cured in clean water for 7, 14, 21 and 28 days in order to determine the compressing strength of the specimen. The slump test results showed that the slump decreases with increase in GSA percentage replacement. The results showed that the compressive strength of OPC/GSA concrete decreases as the percentage of the GSA in the concrete increases for all the tests. Also, the strength of the concrete increases with the increase in the days of curing. The average compressive strength value of 10% GSA replacement in the concrete gave highest strength value of 10.41 MPa and 12.37 MPa for 7 and 14 days test respectfully. While the average compressive strength value of 5% GSA replacement in the concrete gave highest strength value of 18.77 MPa and 20.35 MPa for 21 and 28 days test respectfully. Consequently, the compressive strength results showed that 5-10% would be most acceptable and considered as the best GSA replacement in concrete and a good development for construction work. The GSA/OPC blending can be used for concrete production, mortar for masonry and plastering, bricks/blocks manufacturing and soil stabilization.

Keywords: Groundnut Shell Ash, Blended Cement, Concrete

Introduction

The continuous increase in the price of Portland cement is attributed to the insufficient production rate of the raw materials when compared with the demand rate in the construction industries (Nwofor and Sule, 2012). The construction industry relies heavily on cement for its operation in the development of shelter and other infrastructural facilities (Alabadan *et al*, 2005). Cement concrete is the most widely used building material due to its satisfying performance in strength requirements and its ability to be moulded into a variety of shapes and sizes. However, Pozzolanic materials have long demonstrated their effectiveness in producing high performance concrete. Artificial pozzolan such as rice husk ash have gained acceptance as supplementary cementing materials in many parts of the world (Adole *et al*, 2011). In recent times, many waste materials like fly ash, periwinkle shell ash, palm oil waste, rice husk ash, corncob ash, millet husk ash and groundnut husk ash have been tried as pozzolans or secondary cementitious materials. These supplementary cementing materials play an important role when added to Portland cement because they usually alter the pore structure of concrete to reduce its permeability, thus increasing its resistance to water penetration and water related deterioration such as reinforcement corrosion, sulphate and acid attack. Therefore, the utilization of groundnut shell ash may reduce the environmental problem resulting from the accumulation of the shells in a large quantity in a particular area. With these reasons, this work evaluated the characteristics strength performance of GSA as partial replacement for OPC in concrete, and the durability aspects of concrete. Concrete durability is defined as the capability of concrete to resist deterioration from freezing and thawing, heating and cooling, the action of chemicals such as deicers and fertilizers, abrasion, or any other environmental exposure (Reddy and Marcellina, 2006).

The high cost of cement, used as binder, in the production of concrete has led to a search for alternative. In addition to cost, high energy demand and emission of carbondioxide (CO_2), which is responsible for global warming, the depletion of lime stone deposits is disadvantage associated with cement production. About 7% CO_2 is released into the atmosphere during cement production, which has a negative influence on ecology and the future of human being arising from global warming (Oluremi, 1990). Groundnut shell exists as agricultural waste, and causes environmental pollution. Groundnut is found in both the urban and rural areas of Nigeria. Groundnut shell is produced widely as a waste material after milling is done. The shell occupies 20–24% of the rough groundnut harvested, although the ratio differs by variety. About 58 tonnes of groundnut shell are generated annually in the world (Nakoo, 1999). Its application in some parts of human life will enhance sustainability of the environment and economic development especially in the developing countries. Moreover, groundnut shell ash production requires less energy demand, compared with cement production. It safes the needed foreign exchange spent on importation of cement or its constituents. The main objective of this study is to assess the suitability of groundnut shell ash as partial replacement for cement in concrete production. It is expected that these materials would give reasonable results such that an optimum result of their combination for concrete production will be obtained.

Materials and Methods

The research was carried out in stages; the first stage involved the sourcing for and preparation of material (that is, groundnut shell). At the second stage, preliminary tests were conducted on the groundnut shell ash calcined at 600^{o}C, with muffle furnace. After that, Concrete cubes (100x100x100mm), beams and cylinders were cast using groundnut shell ash (GSA) as partial replacement for cement at different substitutions level and subsequently cured in clean water for 7, 14, 21, and 28 days. All the tests were carried out on the materials, in the Department of Civil Engineering, University of Ibadan, Oyo state, Nigeria.

Materials

The materials used in this project are kersting groundnut shell ash, sand (fine aggregate), granite (coarse aggregate), cement and water as the mixing and curing medium. Groundnut shell used for this research was sourced from Ajegunle market, Saki Oyo State. The shells were collected in bags and transported to the Federal Institute of Industrial Research, Oshodi, Lagos, Nigeria where the calcination and grinding were done. Consequently, the ashes were collected in bags and taken to the Concrete and Structural Laboratory. The sieve analysis, moisture content and the specific gravity were carried out on GSA at the Soil Mechanics Laboratory. The sample of GSA is shown in Plate 1.

Plate 1: GSA

Fine and Coarse Aggregate

The fine aggregate used was white sand obtained from Ajibode River with 4.75mm maximum sieve size. Before the sand was used it was dried to remove the moisture content so that it would not increase the water content in the concrete mix. Also, the coarse aggregate used was granite stone. It is of high quality and free of deleterious organic matter and the 20mm maximum sieve size was used for its size distribution.

$$\% \text{ retained on each sieve} = \frac{\text{weight of soil retained in sieve}}{\text{Total weight of soil}} \times 100\% \quad (1)$$

Cumulative retained= Sum of percentages retained on all coarse sieve

% passing = 100% - cumulative

$$\text{Coefficient of uniformity, } C_u = \frac{D_{60}}{D_{10}} \quad (2)$$

$$\text{Coefficient of curvature, } C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} \quad (3)$$

Experimental Investigations

In this research, a mix ratio of 1:2:4 (Binder: fine aggregate: coarse aggregate) by mass was adopted and OPC/GSA ratio of 100:0, 95:5, 90:10, 85:15, 80:20 and 75:25 percentages by mass was used to investigate the effect of GSA replacement on the concrete. 72 concrete cubes were cast and cured in the curing tank containing clean water to run the test. The compressive strength of the cubes was obtained from the crushing tests at ages 7, 14, 21 and 28 days of curing.

Concrete Batching, Mixing and Curing

The technical act of quantifying the raw materials for the making of fresh concrete, using a basic standard (i.e. a mix ratio) to achieve a reasonable degree of consistence of the fresh concrete and a reliable strength development of its hardened form, was performed on a spacious flat surface with the aid of a standard weighing balance. The standard quantity of materials that was required to produce 1 m^3 of concrete, for a mix ratio of 1:2:4 are 238 kg of cement (0.14 m^3), 0.29 m^3 of sand and 0.57 m^3 of granite. And the approximate volumes for buckets (20 litres paint bucket) are 1 bucket of binder, 2 buckets of sand, 4 buckets of granite. The water/cement ratio used for this project is 0.6, i.e. 30 litres of water for 50 kg of cement.

The primary objective of coating the surface of all aggregate particles with cement paste and the blending of all the ingredients into a uniform mass was achieved as follows; The already batched sand and Cement/GSA were spread on a clean level hard surface where it was uniformly mixed together. Then, the granite batched was spread on top. The accurately quantified clean water was periodically added, according to the water/cement ratio (0.60), as the mixing proceeds until a uniform blend was formed as shown in Plate 2. This procedure was repeated for each of the classes of varying percentage of GSA replacement.

The moulded concrete cubes, beams and the cylindrical specimens were given 24 hours to set before de-moulding. The concrete specimens were marked for identification prior to de-moulding. And then placed in clean water for curing.

Plate 2: Concrete mixing

Workability Tests on Fresh Concrete

Slump and compacting factor tests were carried out on the fresh concrete to determine the workability of each mix. The tests were done in accordance with the requirement of BS EN 12350, part 2 (2019) for slump test and BS EN 12350, and part 4 (2019) for compacting factor test.

Aggregate Impact Value

According to BS 812: Part 112: 1990, two procedures are available for the determination of aggregate impact value, one in which the aggregate is tested in a dry condition, and the other in a soaked condition. The former was adopted in this research. Aggregates passing at 14.0 mm test sieve and retained on a 10.0 mm test sieve were used for the test as stated in BS 812: Part 112: 1990.

$$AIV = \frac{M_2}{M_1} x\ l00 \tag{4}$$

Where, M_1= the mass of the test specimen (in g) and M_2 = the mass of the material passing the 2.36 mm test sieve (in g)

Aggregate Crushing Value

The test specimen was compacted in a standardized manner into a steel cylinder fitted with a freely moving plunger in 3 layers. The specimen was then subjected to a standard load of 400kN apply through the plunger for 10 minutes.

Specific Gravity Determination

Specific gravity bottles, weighing balance, distilled water and a drying cloth were used in the determination of Specific gravity of GSA.

Compressive Strength Test

The compressive strength test was carried out as specified by BS EN 12390; part 3:2019. Sets of 100x100x100mm cubes were used for the determination of compressive strength of GSA blended cement concrete.

Results and Discussion

The results obtained from the preliminary tests and other tests carried out on both fresh and hardened concrete are presented and discussed below.

Specific Gravity

The specific gravity of GSA (1.54) was less than that of the OPC (3.15) it replaced, this means that a considerable greater volume of cementitious materials will result from mass replacement and the chemical compositions of both GSA and OPC.

Table 1: Physical Properties of GSA

Properties	value
Moisture content	0.42%
Specific gravity	1.54

Table 2: Chemical Analysis of GSA and OPC

Constituent	% Composition (GSA)	% Composition (OPC)
Ferrous Oxide (Fe_2O_3)	1.80	4.60
Silica (SiO_2)	16.21	22.00
Calcium Oxide (CaO)	8.69	62.00
Aluminium Oxide (Al_2O_3)	5.93	5.03
Magnesium Oxide (MgO)	6.74	2.06
Sodium Oxide (Na_2O)	9.02	0.19
Potassium Oxide (K_2O)	15.73	0.40
Sulphite (SO_3-)	6.21	1.43
I.L	4.80	2.82

Sieve Analysis of GSA

The sieve analysis done on GSA showed that D60 = 0.37mm, D30 = 0.31mm and D10 = 0.19mm from the graph shown in figure 1. Cu = 1.95 Cc = 1.37. Since 100% passes 4.75mm and 0% retained on 0.075mm, it is categorized as class of sand. Also, since Cu = 1.95 which is less than 6, it is classified as poorly-graded sand (SP) according to USCS (ASTM D2487) classification.

About 67% of the GSA is between 0.300mm and 0.425mm. Cu = 1.95 shows that particles are almost the same size. 0.00% passing 0.075mm sieve means it is coarser than typical pozzolanic materials used for cement replacement. This caused the GSA to be taken to laboratory for grinding.

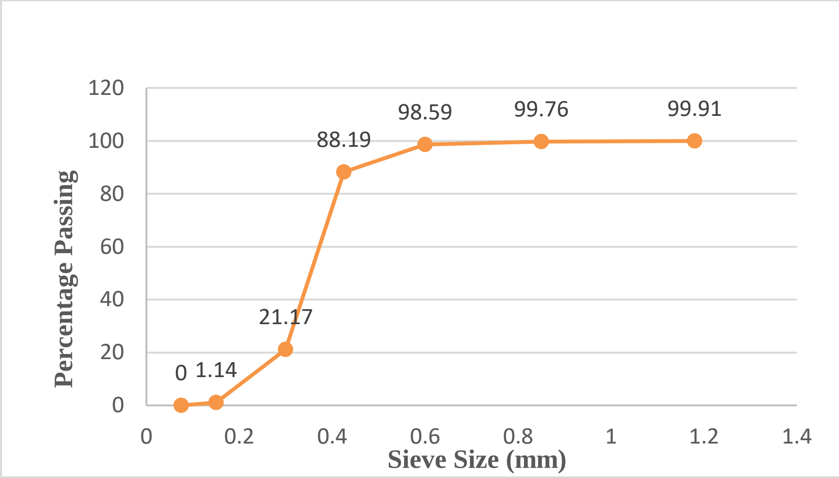

Figure 1: GSA Sieve Analysis - Particle Size Distribution

Sieve Analysis of Fine Aggregate

The particular size distribution of fine aggregate showed the key gradation values that D60 = 1.0mm, which means that the 60% of particles are finer than this. D30 = 0.58mm, that is 30% of particles are finer than this. D10 = 0.25mm, showing that 10% of particles are finer than this. Cu = 4.0 and Cc = 1.35.

90.8% particles passes 4.75mm sieve, which shows that major part is sand (fine aggregate), and 9.2% retained is gravel portion . Also, it is a clean soil since 0% passes 0.150mm sieve. Moreover, Cu = 4.0 which is less than 6, it is classified according to USCS (ASTM D2487) classification as poorly –graded sand (SP). With 9.2% gravel, it is fully called poorly –graded sand with gravel.

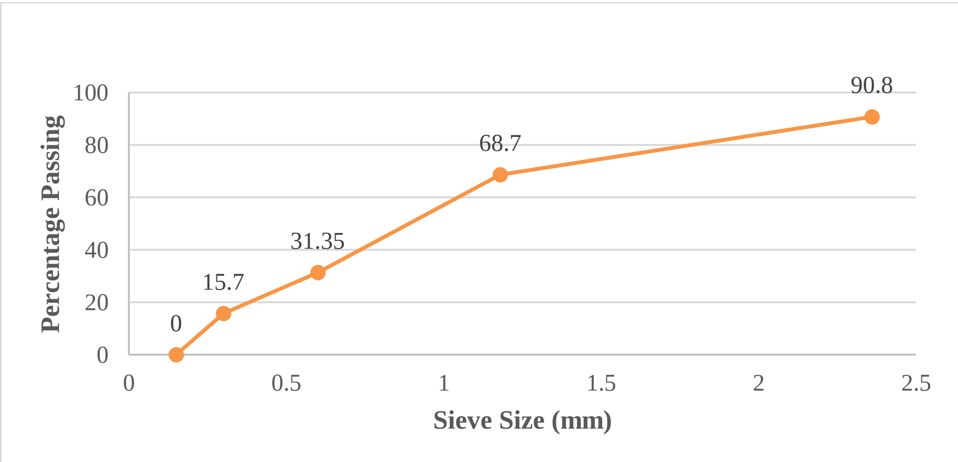

Figure 2: Fine Aggregate Sieve Analysis - Particle Size Distribution

Sieve Analysis of Coarse Aggregate

The gradation parameters are D60 = 11.8mm, D30 = 10.4mm, D10 = 9.2mm, Cu = 1.28, Cc = 0.99. In accordance with USCS (ASTM D2487) classification, the soil is classified as gravel since 100% particles retained on 4.75mm sieve. Cu is 1.28 which is less than 4, it doesn't meet well –graded gravel (GW) criteria, therefore it is a poorly –graded gravel (GP). The graph in figure 2 shows that the curve is near-vertical from 12mm to 10mm. the steep drop indicates very uniform size.

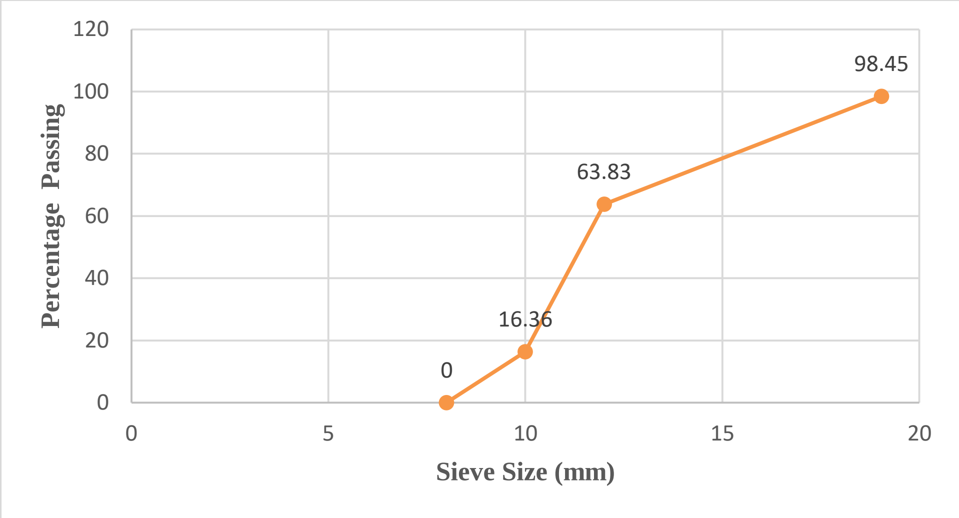

Figure 3: Coarse Aggregate Sieve Analysis - Particle Size Distribution

Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV)

Aggregate impact value measures the resistance to sudden impact /blow, while aggregate crushing value measures the resistance to gradual crushing load. The tests carried out on the aggregate used in this study, gave results shown in Table 3 as thus; AIV = 28% and ACV = 27%. These results conform to standard limits for structural concrete <30% (BS 812 Part 112). For concrete not subject to wear, AIV up to 30% is okay (Shetty 2005). Although higher than values for fresh granite which is 15-20%, the aggregate is suitable for normal reinforced concrete work including GSA-blended mixes. The values indicate moderate weathering, hence the aggregate is not recommended for wearing surfaces without further testing.

Table 3: AIV and ACV Test Results

	AIV Test	ACV Test
M1 (g)	639	760
M2 (g)	179	208
AIV (%)	28	-
ACV (%)	-	27

Slump Test

The slump test results showed the workability of concrete as OPC was being replaced with GSA from 0% to 25%. The slump decreases with increase in GSA percentage replacement. It dropped from 4.93cm at 0% GSA to 2.1cm at 25% GSA, which showed a 57% loss in slump as shown in figure 4. The decrease of the slump with GSA may be caused by the following factors;

1. Lower Density: The specific gravity of GSA is 1.54, which is lower than that of OPC which is 3.15. Replacing by weight causes more paste volume, but that paste is less fluid.
2. Higher Water Demand: GSA particles are irregular and have high specific surface plus carbon content from incomplete combustion. They absorb more mix water.
3. Delayed Setting /Pozzolanic Activity: At early stage, GSA acts mostly as filler. It doesn't lubricate as cement does.

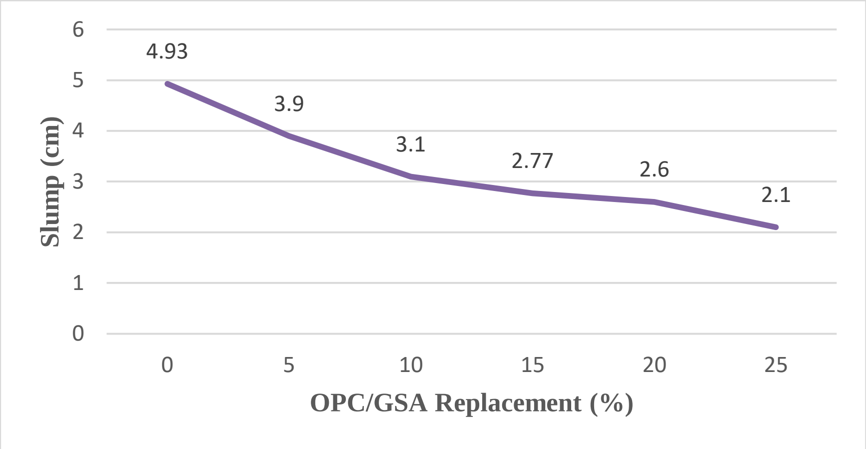

Figure 4: Slump Test (mix 1:2:4)

Compressive Strength Test Results

Table 4 shows that the compressive strength of OPC/GSA concrete decreases as the percentage of the GSA in the concrete increases for all the tests. This simply means that GSA is not effectively compensating for the OPC removed. Though, the concrete strength increases with the increase in the days of curing for all the tests. This is because the hydration of cement and ash possesses little cementing properties compared with Portland cement. At 0% GSA that served as control for other tests, compressive strength increased from 11.94 MPa at 7 days to 23.73 MPa at 28 days, which was 98.7% strength gained. According to BS 8110 (1985), normal OPC concrete typically gains 80-120% from 7 days and 28 days for context. That showed that the 0% GSA mix at 98.7% was right in the expected range for standard hydration.

The compressive strength value for 7 days results decreases from 11.94 MPa of OPC concrete to 7.49 MPa of OPC/GSA concrete. The average compressive strength value of 10% GSA replacement in the concrete gave 10.42 MPa, as the highest most preferable percentage to be used for GSA replacement. For 14 days test, it decreases from 16.53 MPa of OPC concrete to 8.88 MPa of OPC/GSA concrete. The average compressive strength value of 10% GSA replacement, also gave the highest strength value of 12.37 MPa. Also, 21days test results revealed that the compressive strength value decreases from 20.65 MPa of OPC concrete to 10.27 MPa of OPC/GSA concrete. The average compressive strength value of 5% GSA replacement gave the highest strength value of 18.77 MPa. Same thing occurred in 28 days test results, as the compressive strength value decreases from 23.73 MPa of OPC concrete to 10.68 MPa of OPC/GSA concrete, and the same average compressive strength value of 5% GSA replacement gave the highest strength value of 20.35 MPa, all shown in Table 4.

FAO, (1986) reported that cement blended with pozzolans would gain between 65 to 95% strength in 28 days. Also reported that their strength normally improve with age, since pozzolans react more slowly than cement due to different components. And at about a year, the same strength is obtained. This behaviour was confirmed by Sideris and Sarva, (2001) and Sengul, et al (2005) that the replacement of OPC by a pozzolanic material usually have beneficial effects on cement’s durability at ages up to 1.5 years. Though if this experiment is extended beyond 28 days, the above may account for the low strength values recorded with addition of ash in the mixture.

Table 4: Average Compressive Strength Test Results

Cube ID	7 Days Load (kN)	7 Days Stress (MPa)	14 Days Load (kN)	14 Days Stress (MPa)	21 Days Load (kN)	21 Days Stress (MPa)	28 Days Load (kN)	28 Days Stress (MPa)
G	119.4	11.94	165.3	16.53	206.5	20.65	237.3	23.73
5G	101.8	10.18	122.8	12.28	187.7	18.77	203.5	20.35
10G	104.2	10.42	123.7	12.37	179.2	17.92	187.6	18.76
15G	94.1	9.41	113.9	11.39	121.0	12.10	158.4	15.84
20G	80.8	8.08	99.9	9.99	121.9	12.19	140.4	14.04
25G	74.9	7.49	88.8	8.88	102.7	10.27	106.8	10.68

4.0 Conclusions

From the results of the tests and analysis carried out in this study, the following conclusions were drawn;

i. GSA is not adequately a suitable material for use as a pozzolan because of its weak pozzolanic reaction. For a good pozzolan, 28d/7d>2.2. This ratio means that the material is contributing significant late-age strength from pozzolanic reaction, and not just cement hydration. But from this study, the 28d/7d ratio value continued decreasing from 2.00 to 1.43 as the percentage of the GSA increases. This means that GSA was not producing much gel after 7 days. Also, the GSA was mostly diluting OPC and absorbed water.

ii. There exists a potential cost reductions in concrete production using GSA as partial replacement for cement.

iii. The compressive strength value of the GSA/OPC blended concrete at 10% replacement level at 7th and 14th day, and 5% replacement level at the 21st and 28th day performed better. This consequently showed that 5-10% of GSA would be acceptable for partial replacement of cement in concrete.

iv. Although the strength of OPC/GSA concrete was lower than that of 100% cement, it can still be used for construction of light load bearing structures.

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