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Strength properties of groundnut shell ash (GSA) blended concrete

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This research work detailed the report of an experimental study into the strength of modified concrete produced from mixes containing partial replacements of Ordinary Portland Cement (OPC) with groundnut shell ash (GSA). The experiments were designed to include two main mixes (with variations in the water/cement ratios) with different percentages by weight of OPC to GSA in the order of 100:0, 95:5, 90:10, 85:15 and 100:0, 90:10, 80:20 for mixes 1:2:4 and 1:2.3:2.6 respectively. For the ratio 1:2:4 mix, a total of 32 concrete cubes of sizes 150 × 150 × 150 mm and 32 cylindrical concrete specimens (100 mm diameter and 200 mm long) were cast and tested. Also, for the 1:2.3:2.6 mix, 24 concrete cubes and 24 cylindrical concrete specimens, with the same sizes as above, were cast and tested at 7, 14, 21, 28 days of curing. Compressive and splitting tensile tests were conducted to assess the strength of concrete. Generally, strengths of modified concrete increased with curing period but decreased with increased GSA percentage. For mix ratio 1:2:4, the highest compressive and tensile strengths were 24.06 (2.67) and 21.34 (2.11 N/mm^2) at 28 days for 0 and 10% GSA respectively. While mix ratio of 1:2.3:2.6 gave the highest compressive and tensile strengths of 35.11 (4.21) and 27.33 (4.01 N/mm^2) at 28 days for 0 and 10% GSA respectively. It was observed that 10% GSA replacement was appropriate for both mixes. GSA therefore seems to be a promising and local partial replacement material for cement in concrete making.

Key words: Concrete, pozzolana, partial replacement, groundnut shell ash (GSA), concrete strength.

INTRODUCTION

Due to increasing industrial and agricultural activities, tones of waste materials are deposited in the environment with little effective method of waste managing/recycling. Some of these deposits are not easily decomposed and the accumulation is a threat to the environment and people at large. Some of these waste materials are rice husks, maize combs, snail shells, palm-kennel shell, coconut shell, saw dust, groundnut shell etc. Global pollution coupled with resource depletion has challenged many researchers and engineers to seek locally available materials with a view to investigating their usefulness wholly as a construction material or partly as a substitute for conventional ones in concrete making. In search for new materials which address the issues aforementioned and which are cost effective and more efficient, pozzolans attract much interest. Malhotra and Mehta (1996) define "pozzolan" as "a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form – an in the presence of moisture -

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chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties." Numerous achievements have been made in these regards and the subject is attracting attention due to its functional benefit of waste reusability and sustainable development, reduction in construction costs and its indigenous technology and equipment requirements are added advantages. Among others, Alabadan et al. (2005) investigated the potentials of Groundnut Shell Ash (GSA) as a partial replacement for ordinary portland cement in concrete. In the study, it was generally reported that the strength of the control was higher and concluded that the replacement of cement with ash up to 30% gave promising results over others. This research intends to investigate the pozolanic activity and usefulness of one of these agricultural waste materials (groundnut shell ash) as a partial substitute for cement in concrete making. If found useful, it will promote waste management/recycling at little cost, reduce pollution by the waste and increase the economic base of the farmer.

Admixture is defined as a material, other than cement, water and aggregates that is used as an ingredient of concrete and is added to the batch immediately before or during mixing (Shetty, 2005)

Blended cement is obtained by adding mineral admixtures like fly- ash, slag and silica fumes to OPC. There are a number of systems that are used to make blended cements. Some systems are capable of "on-demand" blending, while others may blend the materials in a fixed percentage into a storage silo. All of the systems meter the constituent products in the desired proportions, and then blend them to a uniform mixture. In most cases, proportions can be adjusted to produce blends that optimize the desired properties in concrete.

MATERIALS AND METHODS

The research was carried out in stages; the first stage involved the sourcing for and preparation of material (groundnut shell), at the second stage, preliminary tests on the groundnut shell ash (calcined at 600°C) was conducted at the Department of Agronomy, University of Ibadan, Ibadan, Nigeria. At the next stage, concrete cubes (150 × 150 × 150 mm) and cylindrical concrete specimens (100 mm diameter, 200 mm length) were cast using groundnut shell ash (GSA) as partial replacement for cement and subsequent tests were carried out on them. The class of specimens is seen in Tables 1 and 2. The concrete comprised of ordinary portland cement (OPC), fine aggregate and coarse aggregate, water and groundnut shell ash (GSA). The ordinary portland cement packaged by Dangote Group was used. It was stored under dry condition and free from lump. The coarse aggregate used was granite stone. It was of high quality and free of deleterious organic matter and only the ones retained on sieve 3.75 mm were used. Also, the fine aggregate used was white sand obtained from river. Groundnut shell was obtained from marketers at Bodija, Ibadan, Oyo- State, Nigeria. About 8 kg of the shells was obtained and burnt to ash completely at temperature 600°C in a furnace at Fine Art Department, The Polytechnic, Ibadan. The ash was then sieved through British Standard sieve of 312 µ after grounding. The portion passing the sieve was reported to the required degree of fineness that is 312 µ and below while the ash retained on the sieve was reground and sieved again.

In this research, a mix ratio of 1:2:4 (cement:fine aggregate:coarse aggregate) by mass was adopted and OPC/GSA ratio of 100:0, 95:5, 90:10, 85:15 percentages by mass were used. Also, high strength concrete (40 Mpa) was designed and OPC/GSA ratio of 100:0, 100:10, 100:20 percentages by mass were used to investigate the effect of GSA replacement on HSC. 32 concrete cubes (150 × 150 × 150 mm) and 56 cylindrical specimens (100 mm diameter, 200 mm length) were cast and cured in the curing tank containing clean water. The compressive and splitting tensile strengths of the cubes and cylindrical specimens respectively were obtained from the crushing and splitting tensile tests at ages 7, 14, 21, 28 days of curing.

Class of specimens

Tables 1 and 2 provide class of specimens.

Preliminary test

This includes tests conducted on the constituent materials used in the production of the specimens.

Chemical analysis of GSA

Chemical analysis of GSA was carried out at Laboratory of the Department of Agronomy, University of Ibadan, Ibadan, Nigeria and the result is presented in Table 3.

Sieve analysis of GSA, fine aggregate and coarse aggregate

Sieve analysis was conducted on the GSA, fine and coarse aggregates used at the Material Laboratory of the Oyo State Secretariat, Ibadan. The sieve were mounted into a frame and shaken in a mechanical sieve shaker for 10 min. The apparatus and materials used were set of sieve (7, 14, 25, 36, 72, 200, 200 for GSA and fine aggregate and ¾", ½", 3/8" for granite), balance sensitive to 0.1 g, brush (for cleaning sieves), mechanical shaker, sample of soil, large pan. The results of the sieve analysis of the GSA, fine aggregate and coarse aggregate are given in Figure 1.

Aggregate impact value (AIV)

According to BS 812: Part 112 (1990), two procedures are available for the determination of AIV, 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 a 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). The test specimen was compacted, in a standardized manner, into an open steel cup. The specimen was tamped and then subjected to 25 numbers of standard impacts from a dropping weight in 3 layers. This action broke the aggregate to a degree which is dependent on the impact resistance of the material. This degree was assessed by a sieving test on the impacted specimen with the use of 2.36 mm sieve. Weights of retain and passing were measured. The result of the test is given in Table 4. AIV was calculated from the equation as follows:

$$AIV = M1/M2 \times 100$$

Where M_1 = the mass of the test specimen (in gram); M_2 = the mass

Table 1. Normal concrete (1:2:4 mix), for compressive test.

Sample	GSA%	7 days	14 days	21 days	28 days
CN_0	0	2	2	2	2
CN_5	5	2	2	2	2
CN_{10}	10	2	2	2	2
CN_{15}	15	2	2	2	2

CN_0 = Compressive test for normal concrete at 0%GSA.

Table 2. Normal concrete (1:2:4 mix), for splitting tensile test.

Sample	GSA%	7 days	14 days	21 days	28 days
TN_0	0	2	2	2	2
TN_5	5	2	2	2	2
TN_{10}	10	2	2	2	2
TN_{15}	15	2	2	2	2

TN_0 = Tensile test for normal concrete at 0%GSA.

Table 3. Chemical properties of GSA.

Constituent	% By weight (g) test 1	% by weight (g) test 2	% by weight (g) average
ZnO	2.56	2.61	2.59
C_uO	1.86	1.89	1.88
Fe_2O_3	2.24	2.27	2.26
MnO_2	3.48	3.53	3.51
MgO	4.86	4.86	4.86
SiO_2	32.96	33.05	33.01
Al_2O_3	7.06	7.06	7.06
K_2O	9.75	9.78	9.77
CaO	11.23	11.18	11.21
Na_2O	6.53	6.55	6.54
Loss on ignition	8.76	8.84	8.80
Others	8.71	8.38	8.55
Total	100	100	100

of the material passing the 2.36 mm test sieve (in gram).

Aggregate crushing value (ACV)

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 400 kN applied through the plunger for 10 min. This action crushed the aggregate to a degree which is dependent on the crushing resistance of the material. The degree was then assessed by a sieving test on the crushed specimen with the use of 2.36 mm sieve. Weights of retain and passing were measured. The result of the test is given in Table 4. ACV was calculated from the equation as follows:

$$AIV = M1/M2 \times 100$$

Where M_1 = the mass of the test specimen (in gram); M_2 = the mass of the material passing the 2.36 mm test sieve (in gram).

Specific gravity determination

Specific gravity bottles, weighing balance, distilled water and a drying cloth were used in the determination of specific gravity of GSA. Empty, clean and dry specific gravity bottle with its stopper was weighed (W1). The bottle was filled up to one-third full with the GSA sample and reweighed (W2). A small amount of distilled water was then added and the bottle contents shaken to remove entrapped air. Shaken continued and more water added until the bottle was full. The stopper was inserted and excess water cleaned on bottle and weighed (W3). The bottle thereafter was emptied, thoroughly washed and wiped dry and then filled with distilled water and the stopper inserted and excess water cleaned and weighed (W4). These procedures were repeated using another bottle for the purpose of obtaining the average. The results are giving in Table 8.

Tests on concrete

Tests were conducted on both fresh and hardened concrete. The

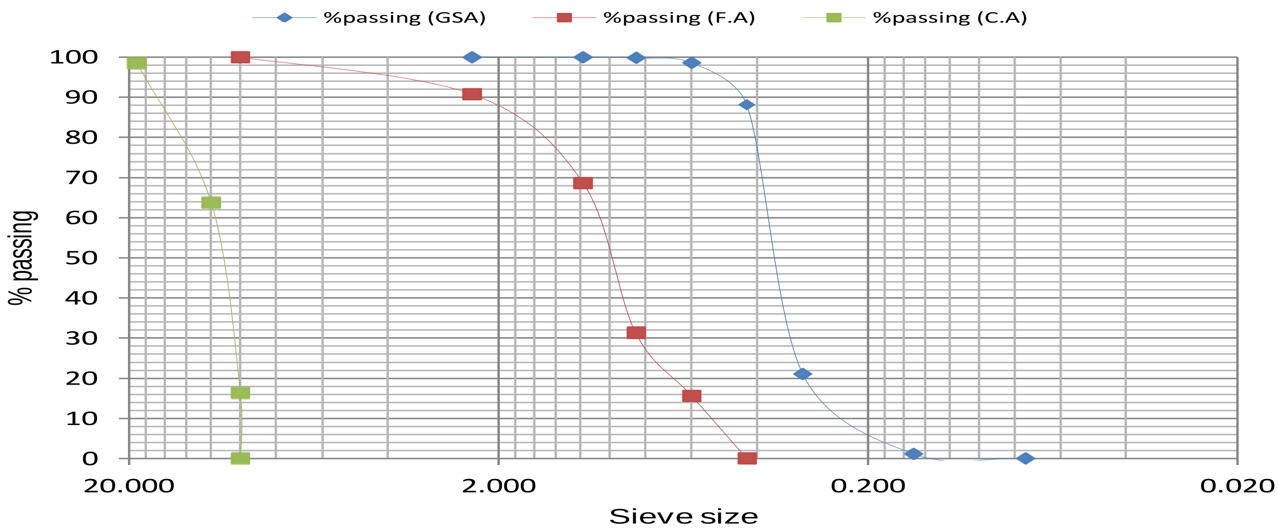

Figure 1. Particle size distribution of aggregates and GSA.

tests are slump test, weight development, compaction factor, compressive strength and splitting tensile strength.

Slump test

A slump cone, straight edge, scoops, steel rule and tamping rod were used. The slump cone was filled with freshly mixed concrete in three approximately equal layers, roding each exactly 25 times while standing the cone on a solid, flat impermeable and clean surface of concreting and bricklaying floor. The final layer slightly protruded above the cone was strike off from the cone while concrete droppings around the base were cleaned. The cone was lifted steadily, vertically and the slump was measured as the difference between the highest points on the slumped concrete and its original level in the cone by inverting the empty cone alongside the slumped concrete, placing a straight edge with a rule; results are shown in Table 6.

Weight development determination

The cubes and cylindrical specimens were weighed before testing and the densities of cubes at different time of testing were measured. Prior to testing, the specimens were brought out of the tank, left outside in the open air for about 2 h before crushing.

Splitting tensile test

Splitting tensile test was conducted at the Mechanical Laboratory of the Polytechnic, Ibadan. After the specimens had been cured for the proper length of time in the water tank, the immersed specimens were taken out from water and allowed to dry. The machine was set for the required range and diametrical lines were drawn on the two ends of the specimen to ensure that they are on the same axial place, after noting the weight and dimension of the specimen. A plywood strip was placed on the lower plate, then the specimen was placed above the lower plate and the other plywood strip was placed above the specimen. The specimen was loaded continuously without shock at uniform rates until failure occurred and the failure load was recorded. The results are given in Tables 9 and 10.

Compressive test

After the specimens had been cured for the proper length of time in the water tank, the concrete cube specimens were crushed at ages 7, 14, 21, 28 days of curing using the compression testing machine available in the Civil Engineering Laboratory of the Polytechnic, Ibadan. The cube was placed between the compressive plates parallel to the surface and then compressed at uniform rate (that is, without shock) until failure occurred. The maximum load at failure and the compressive strength were read through the screen at the top of the machine. The compressive strength was manually calculated by dividing the maximum load in Newtons (N) by the average cross sectional area of the specimen in square millimeters (mm^2) (Tables 7 and 8).

RESULTS

The chapter presents and discuses the results obtained from the preliminary test, tests carried out on both fresh and hardened concrete.

Chemical analysis of GSA

Chemical analysis of GSA is given in Table 3.

Sieve analysis of GSA, fine aggregate and coarse aggregate

The graph of the sieve analysis of the GSA, fine aggregate and coarse aggregate is given in Figure 1.

Aggregate impact value (AIV) and aggregate crushing value (ACV)

This is given in Table 4 Where M_1 = the mass of the test

Table 4. Result of AIV and ACV tests.

	Aggregate impact test	Aggregate crushing test
W1 (g)	642	759
W2 (g)	177	205
AIV (%)	28	-
ACV (%)	-	27

Table 5. Result of specific gravity of G.S.A.

Sample weight	Test A	Test B
W1	25.60	25.30
W2	60.12	59.59
W3	80.20	80.10
W4	68.24	68.00
G	1.54	1.55

specimen (in gram); M_2 = the mass of the material passing the 2.36 mm test sieve (in gram). Both AIV and ACV were calculated from the equation as follows:

$$AIV = \frac{M1}{M2} \times 100$$

Specific gravity determination

Table 5 gives result of specific gravity determination.

$$S.G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

Where W1 = weight of empty flask, W2 = weight of flask + cement, W3 = weight of flask + cement + water, W4 = weight of flask + water. Average = 1.54.

Slump test result

Table 6 and Figure 2 shows that the slump decreases with increasing %GSA replacement for both mixes.

Compressive test

Tables 7 and 8 and Figures 3 and 4 shows results of the compressive test.

Splitting tensile test

Tables 9 to 12 and Figures 5 to 8 shows results of the splitting tensile test.

DISCUSSION

Table 3 shows that groundnut shell ash contains the main chemical constituents of cement. ASTM C-618 (2007) specifies that any pozzolan that will be used as cement replacement in concrete requires a minimum of 70% for SiO_2, Al_2O_3 and Fe_2O_3 and that silica, of all the oxides, which is normally considered the most important, should not fall below 40% of the total. From Table 3, the total amount of SiO_2, Al_2O_3 and Fe_2O_3 was 54.79% which was less than the value specified by ASTM C-618 (2007). However, since calcination temperature has significant effect on these three oxides, GSA could still be a good and suitable pozzolan, when it is calcined at higher or lower temperature than 600°C. The particle size distribution of GSA, fine and crushed granite is shown in Figure 1. The uniformity coefficient for crushed granite is greater than 4.0, which implies that the material is suitable for concrete works and its coefficient of curvature of 1.1 lies within the required range of values that is, 1.0 and 3.0. The S-shaped curve of sand and GSA shows that it is well graded. BS 812: Part 110 and Part 112:1990 specify that ACV and AIV respectively should not be greater than 30% for construction purpose. The ACV (27%) and AIV (28%) from Table 4 fall within the acceptable limit (that is, 30% and below), which implies that the aggregate used in this research is suitable for concrete works. The specific gravity of the 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. It was observed that the splitting tensile strength increases with curing age but decreases with GSA inclusion. Tensile strength was roughly about 10% of compressive strength, this agrees with the specification of BS 8110.

The compressive strengths of concrete cube specimens for different percentages of GSA are shown in the Figures 3 and 4 for concrete mixes 1: 2:4 and 1:2.3:2.6. For each mix, compressive strength decreases as GSA contents increases (that is, as percentage of cement decreases). Generally, compressive strength increases with curing age for both mixes. For 1:2:4 concrete mix, 0% ash (100% cement) that served as the control, strength increased from 10.80 N/mm^2 at 7 days to24.06 N/mm^2 at 28 days that is about 140% increment. At 5% ash, strength increased by 140% while increments

Table 6. Results of slump test on concrete with GSA partial replacement (1:2:4 and 1:2.3:2.6 mix).

OPC/GSA	0%	5%	10%	15%	20%
Slump 1:2:4 mix (mm)	30	23	18	15	-
Slump 1:2.3:2.6 mix (mm)	20	-	15	-	13

Table 7. Compressive test result for normal concrete 1:2:4 mix.

Sample	GSA%	7 days	14 days	21 days	28 days
CN_0	0	10.80	13.29	17.91	24.06
CN_5	5	9.29	12.30	18.32	21.34
CN_{10}	10	10.50	12.20	16.35	22.33
CN_{15}	15	8.23	10.23	11.33	15.34

Table 8. Compressive test result for HSC (1:2.3:2.6).

Sample	GSA%	7 days	14 days	21 days	28 days
CH_0	0	14.05	19.34	27.11	35.11
CH_{10}	10	10.11	19.11	22.34	27.33
CH_{20}	20	8.16	17.74	16.56	21.34

Table 9. Splitting tensile test result for normal concrete (1:2:4).

Sample	GSA%	7 days	14 days	21 days	28 days
TN_0	0	1.01	1.48	2.01	2.67
TN_5	5	0.54	1.15	1.86	2.56
TN_{10}	10	1.46	1.30	1.64	2.11
TN_{15}	15	0.88	0.95	1.15	1.99

Table 10. Splitting tensile test result for HSC (1:2.3:2.6).

Sample	GSA%	7 days	14 days	21 days	28 days
TH_0	0	2.36	2.61	2.72	4.21
TH_{10}	10	1.20	1.11	4.33	4.01
TH_{20}	20	0.98	1.74	1.56	2.80

Table 11. Compressive and splitting tensile strengths of concrete compared (normal concrete, 1:2:4).

Sample	GSA%	7 days	14 days	21 days	28 days
CN_0	0	10.80	13.29	17.91	24.06
TN_0	0	1.01	1.48	2.01	2.67
CN_5	5	9.29	12.30	18.32	22.33
TN_5	5	0.54	1.15	1.86	2.56
CN_{10}	10	10.50	12.20	16.35	21.34
TN_{10}	10	1.46	1.30	1.64	2.11
CN_{15}	15	8.23	10.23	11.33	15.34
TN_{15}	15	0.88	0.95	1.15	1.99

Table 12. Compressive and splitting tensile strengths of concrete compared (HSC, 1:2.3:2.6).

Samples	GSA%	7 days	14 days	21 days	28 days
CH_0	0	14.05	19.34	27.11	35.11
TH_0	0	2.36	2.61	2.72	4.21
CH_5	10	10.11	19.11	22.34	27.33
TH_{10}	10	1.20	1.11	3.33	4.01
CH_{20}	20	8.16	17.74	16.56	21.34
TH_{20}	20	0.98	1.74	1.56	2.80

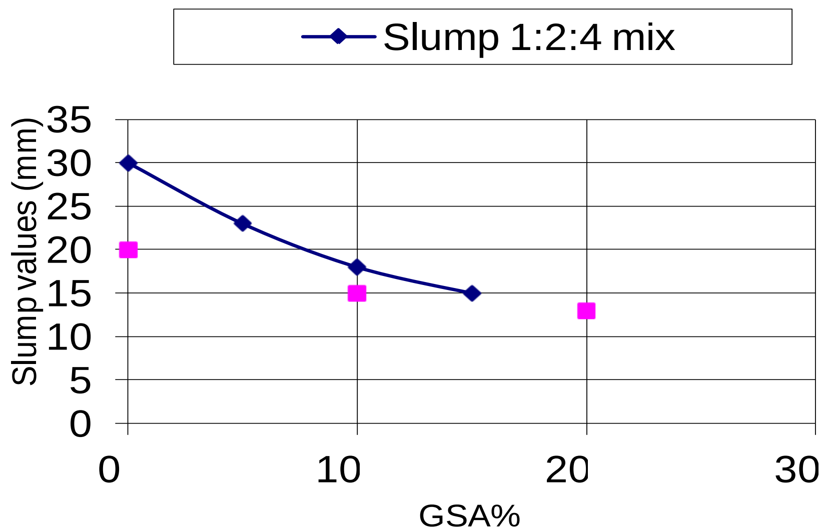

Figure 2. Slump value for various percentages of GSA in concrete 1:2:4 and 1:2.3:2.6 mixes.

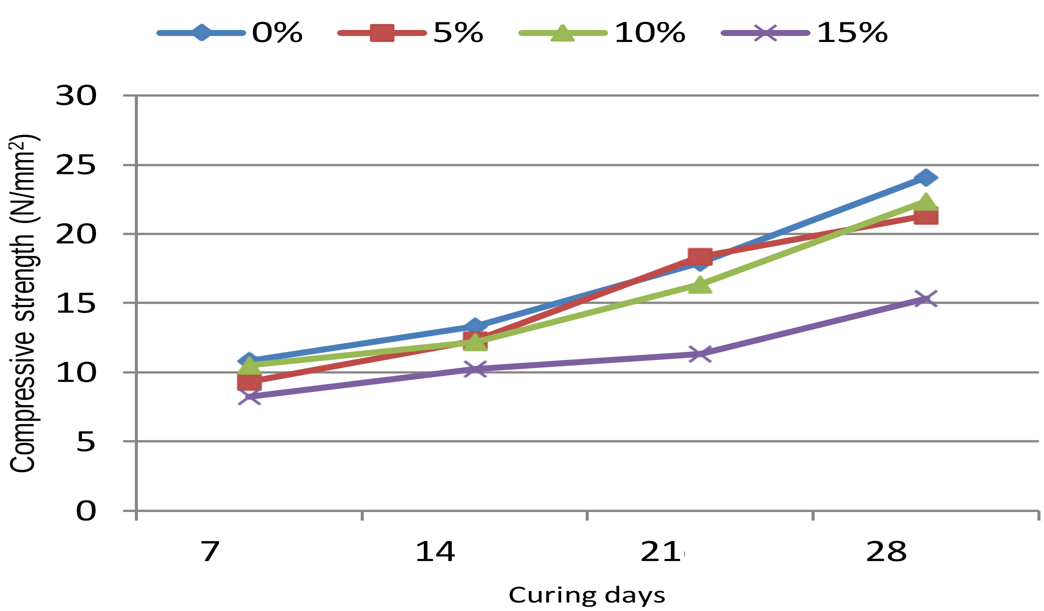

Figure 3. Compressive strength variation with different percentages of GSA in concrete with mix 1:2:4.

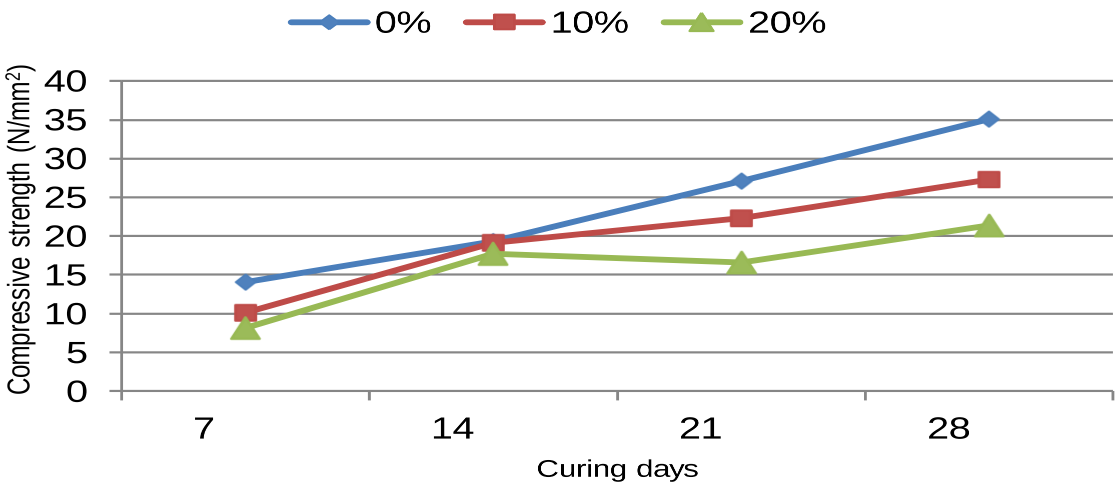

Figure 4. Compressive strengths variation with different percentages of GSA in concrete with mix 1:2.3:2.6.

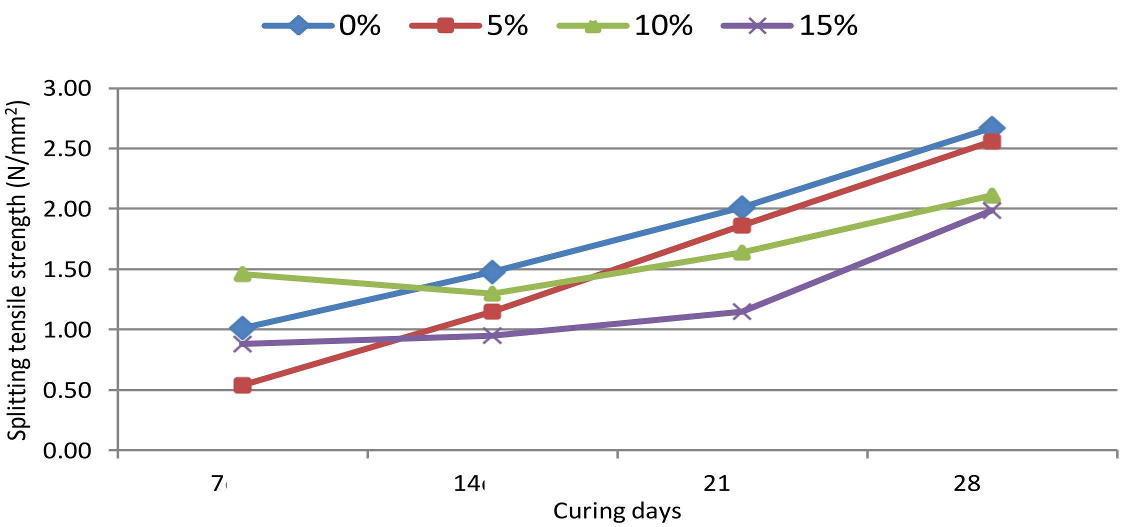

Figure 5. Splitting tensile strength variation with different percentages of GSA in concrete with mix 1:2:4.

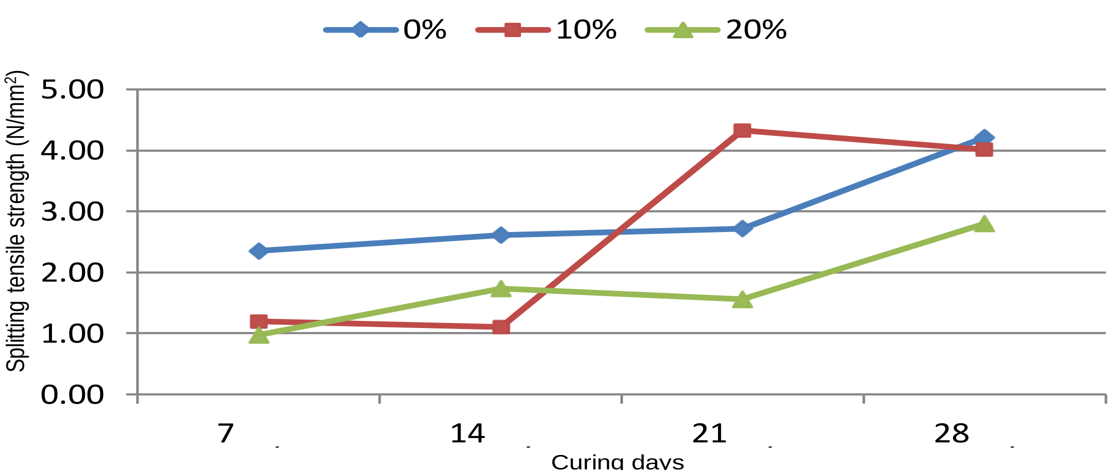

Figure 6. Splitting tensile strengths variation with different percentages of GSA in concrete with mix 1:2.3:2.6.

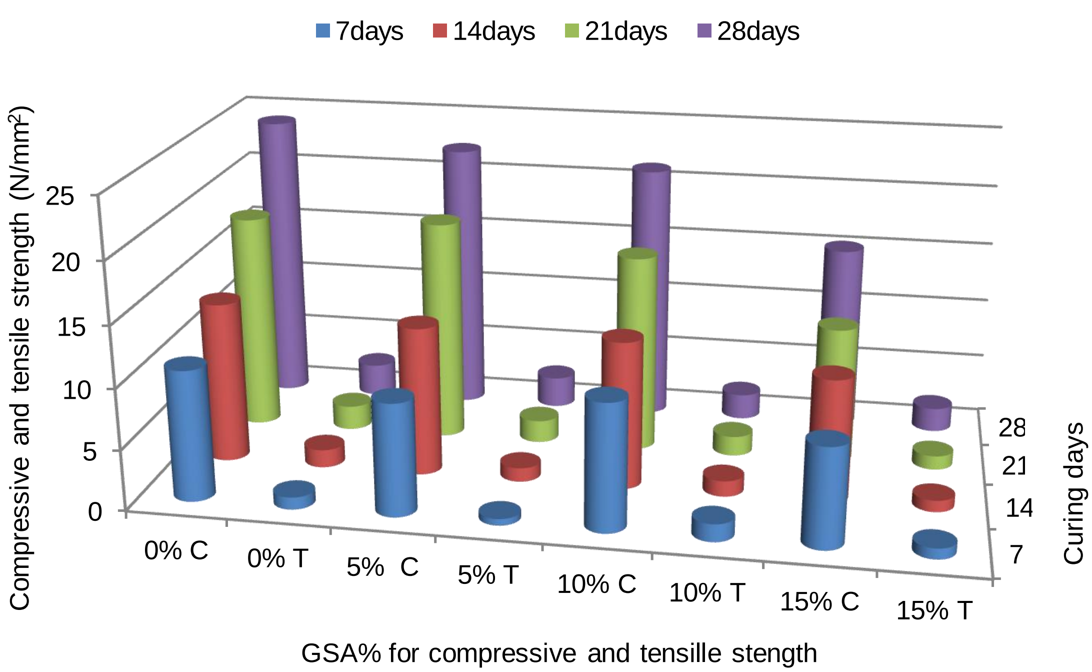

Figure 7. Compressive and splitting tensile strength of concrete compared (normal concrete, 1:2:4).

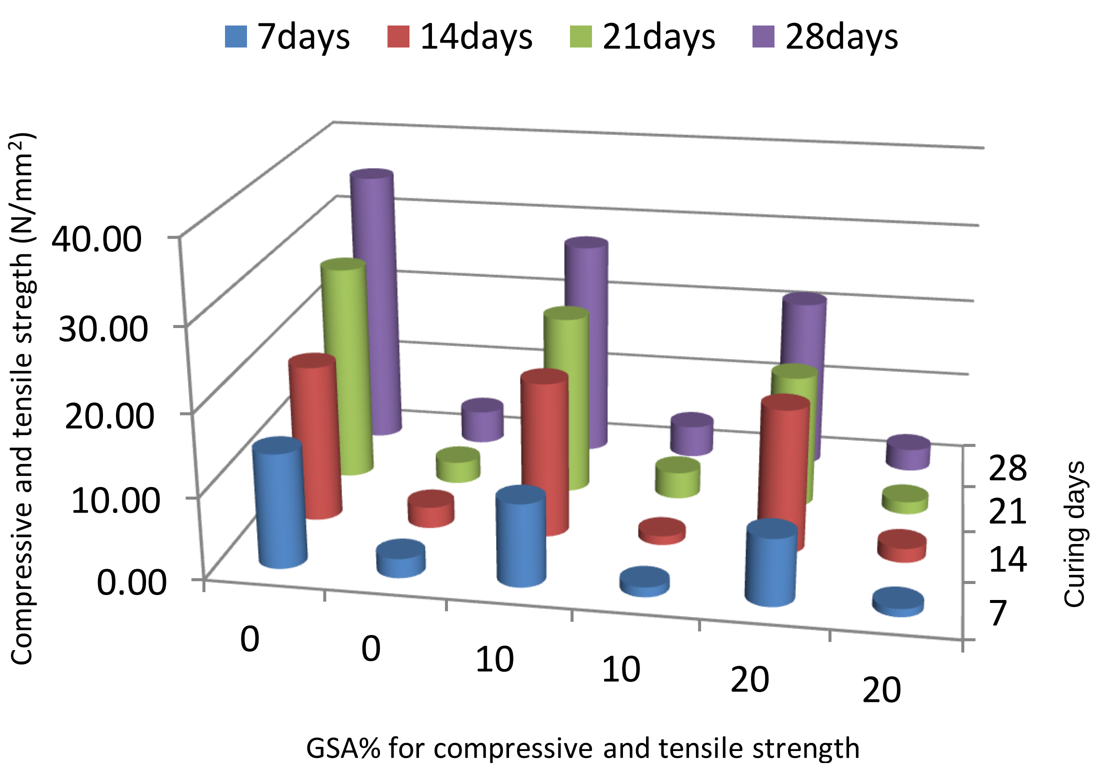

Figure 8. Compressive and splitting tensile strength of concrete compared (HSC, 1:2.3:2.4).

of about 150 and 130% were recorded with 10 and 15% ash respectively from 7 to 28 days curing period. For 1:2.6:2.3 concrete mix, the same trend of increments was observed. Though, the results of OPC/GSA concrete was lower than that of 100% cement in both cases, it can be used for light load bearing elements.

Conclusion

The following conclusions are drawn after this study which investigated the strength performance of modified concrete with groundnut shell ash (GSA). It was discovered that the groundnut shell ash contains all the main chemical constituents of cement though in different proportions compared to that of OPC. This means it will be a good replacement for cement, if the optimum calcinations temperature is established and the right proportion is used:

(1) The experimental results showed that GSA is a good pozzolanic material which reacts with calcium hydroxide forming calcium silicate hydrate. The pozzolanic activity of GSA increases with increase of time.
(2) The slump values for both concrete mixes show that the slump decreases with increasing GSA replacement.
(3) The specific gravity of the GSA gotten was less than that of the OPC it replaced, this means that a considerable greater volume of cementitious materials will result from mass replacement.
(4) Though the strength of OPC/GSA concrete was lower than that of 100% cement, it can be used for light load bearing elements.

RECOMMENDATIONS

The following recommendations are made for further investigations:

(1) Superplasticicer should be introduced so that early strength could be generated and lower water/cement ratio is maintained.
(2) Other test such as corrosion resistance, shrinkage properties, and absorption rate should be carried out on the GSA concrete.
(3) It is recommended that the concrete curing should be extended beyond 28 days to ascertain the long term strength development of ash modified concrete.
(4) GSA calcinations temperature should be varied to establish optimal temperature for pozzolanic activity of GSA.

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