Nigerian Journal of Technology (NIJOTECH)
Vol. 31, No. 2, July, 2012, pp. 111–115.
 ISSN 1115-8443

COMPARATIVE COST AND STRENGTH ANALYSIS OF CEMENT AND AGGREGATE REPLACEMENT MATERIALS

C.S. Adaba[a], J.C. Agunwamba[b], C.U. Nwoji[c], O.E. Onya, S. Ozeh

Department of Civil Engineering, University of Nigeria, Nsukka, Nigeria.
Emails: [a]realsandra@rocketmail.com; [b]jcagunwamba@yahoo.com; [c]cunwoji@yahoo.com

Abstract

This research presents a comparative cost and strength analysis of cement and aggregate replacement materials which is aimed at reducing the cost of concrete production. Tests were performed to compare the strength and cost of seven various cement replacement materials(rice husk ash, groundnut husk ash, palm oil fuel ash, bone powder ash, acha husk ash and bambara groundnut shell ash); six aggregate replacement materials (palm kernel shell, quarrydust, crushed spent fire bricks, periwinkle shell, recycled concrete and recycled rubber tyres) were used. Various concrete cubes of 100mm, 150mm and 225mm thickness were prepared using water/cement ratio of 0.35 and a mix design of 1:1.5:3 batching by weight was adopted. The cement and aggregate replacement materials were varied at different proportions and percentages during mixing. Samples were tested for 7, 14 and 28day strength. The following test were performed on cube samples for both physical and mechanical properties; particle size distribution, slump test, consistency, setting time test, water absorption test, compressive strength and marshal stability test. The analysis of the results showed that bone ash cement replacement material had the highest 28day strength but the rice husk ash appears to be more promising due to its low cost and availability as well as high strength value. Compressive strength at 28 day of crushed spent fire brick aggregate as partial replacement material was higher than the conventional river sand. Periwinkle shell can only be used as light weight aggregate. The cost of using conventional aggregate can be reduced to about 30% when palm kernel shell and quarry dust are used as partial replacement for aggregate. This study suggests that; the cost of construction and concrete production can be reduced if cement and aggregate replacement materials are used.

Keywords: cement replacement material, aggregate replacement material, low Cost

1. Introduction

Cement refers to bonding agents that are mixed with water and other liquid to produce a cementing paste. Concrete is mostly used in both construction and building industries and the cost of concrete production is relatively high due to the manufacture of its main constituent (Ordinary Portland Cement). For every 1ton of cement produced, some quantities of CO2 is released into the atmosphere. To produce 1ton of cement, 1.6 ton of natural resources are consumed [1].

Ordinary Portland cement are mostly used but due to varying construction conditions and other factors, there exist pozzolanic cement. Palm oil fuel ash, rice husk ash and wood ash contains pozzolanic material thus; they can be used as cement replacement material since; their chemical composition meets the standard of ASTM. Adding pozzolanas as cement replacement material to concrete would reduce the slump and increase the water demand due to the high fineness of these replacement materials.

[2] stated that; incorporation of palm oil fuel ash as partial cement replacement in concrete will increase the chemical resistance to acidic environment. Most studies concluded that addition of pozzolanas will increase shrinkage in concrete. The result of a study carried out by [3] showed that, palm kernel husk ash (PKHA) reduces the setting time of OPC cubes prepared with a mxture of PKHA and OPC.

According to the ASTM standard, the bone ash does not meet the requirement of been classified as pozzolana due to the high content of calcium oxide.

Maximum economy is achieved when aggregates are used and its use considerably improves both the volume stability and durability of the resulting concrete [4]. Aggregates are classified as fine when the particle size is less than or equal to 0.0063m and coarse when the aggregate size is roughly 0.0635m or more. As a general rule, the largest size particle of aggregate should not exceed 1/5th the distance across the narrowest parts of its form. Periwinkle shell is a form of light weight aggregate which can be used as partial replacement material for sand. In some parts of Nigeria, periwinkle shells are used as conglomerate in the production of concrete.

Water plays an important role in the production of concrete; it converts the dry concrete and aggregate into plastic and workable form. Concrete expands slightly during setting due to hydration of cement and shrinks on subsequent drying. It is well known that the strength of concrete is closely dependent upon the water/cement ratio [5].

According to a statement by [6], quarry dust are either light weight or high density aggregate. Quarry dust material intended for use as fine aggregate should be defined as material less than 4mm size unless it is to be used in asphalt [7].Concrete strength of up to 80N/mm2 can be achieved by selective use of the type of cement, mix proportion, aggregate particle size, shape, texture, method of compaction and curing conditions [5].

Due to the high demand for concrete in construction and building industries, the use of conventional aggregates has drastically reduced the natural stone deposits thereby; causing an ecological imbalance of the environment. However, there is need to explore other suitable materials as substitute for the conventional cement and aggregate material.

The objectives of this paper are to:

1. Analyse various types of cement and aggregate suitable for use as partial replacement for conventional materials
2. Determination of both physical and mechanical properties of the various concrete made of cement and aggregate replacement materials and compare results
3. Carry out cost analysis on selected cement and aggregate replacement material and compare results with that obtained by using conventional cement and aggregate material
4. Make recommendations based on the results on the best and suitable cement and aggregate replacement material.

2. Materials and Methods

Materials used for this research includes; Ordinary Portland Cement (OPC), Rice Husk Ash (RHA), Groundnut Husk Ash (GHA), Bone Powder Ash (BPA), Wood Ash (WA), Palm Oil Fuel Ash(POFA), Acha Husk Ash (AHA), Bambara Groundnut Shell Ash(cement replacement materials), conventional fine and coarse aggregate(sand and gravel), periwinkle shell, palm kernel shell, recycled concrete, crushed spent fire bricks and recycled tyres (aggregate replacement materials).

3. Sample Preparations and Tests

For the purpose of this research, the cement replacement materials were burnt at temperature ranging from 438 to 900°C and ground into fine powder after cooling ;this were passed through 212micro B.S Sieve with exception of wood ash and bambara ash which passed through 75micro B.S sieve. Concrete cubes were cast using water/cement ratio of 0.35 and a mix design of 1:1.5:3 the constituents were thoroughly mixed to ensure uniformity. Partial replacement of both cement and aggregate materials of various types were varied within the range of 0-40%. Concrete were placed on the mould and compacted thereafter, the cubes were left at room temperature for 24hrs before being transferred into the curing tank. The water/cement ratio used for the periwinkle gravel concrete was 0.5 to produce cubes of 150mm thick. Proportions of periwinkle shell to gravel are in the ratios of 0:1, 1:0, 1:1, 3:1 and 1:3. Same procedure is applicable to concrete made from crushed spent fire bricks and recycled concrete as partial replacement for coarse aggregate. For the production of asphalt concrete, 4% filler of size 0.075mm, 35% stone dust of 5mm, 6% river sand of 5mm, 20% crushed stone of 5mm to 16mm and 35% crushed stone of 16mm to 27mm together with 5% bitumen of grade 60-70 were thoroughly mixed before the addition of palm kernel shells at varying percentages ranging from 10-70% the mixture was compacted in a cylindrical mould.

The specimens were tested for both physical and mechanical properties and the tests carried out on the hardened concrete include: particle size distribution, water absorption test, consistency and setting time test, slump test, compressive strength test and marshal stability test. All the tests were performed in accordance to the British Standard.

4. Results and Discussion

Results obtained from the strength and cost analysis of the various types of cement replacement materials showed that the bone powder ash had the highest compressive strength due to its large amount of C3S while, rice husks ash had the highest value of C2S .The Bogue model was used to compute the compound composition of cement replacement materials as shown in tables 1 and 2. The rice husk ash best satisfies the cost requirement since its cost

Table 1: Percentage Bogue Compound Composition of Main Compounds in Various Binder Materials.

	POFA 10%	RHA 30%	BPA 10%	AHA 20%	GHA 10%	BGSA 10%	WA 20%	Control
C3S	1.57	-125.04	52.39	-25.70	-20.20	23.31	-35.69	50.7
C2S	31.0	193.81	14.88	90.14	84.22	45.54	92.69	22.5
C3A	8.093	11.14	11.4	10.91	19.74	10.02	22.86	8.6
C4AF	10.114	6.19	7.24	7.54	8.15	7.5	7.5	9.4

* POFA=Palm Oil Fuel Ash, RHA=Rice Husk Ash, AHA=Acha Husk Ash, BGSA=Bambara Groundnut Shell Ash, GHA=Groundnut Husk Ash, BPA=Bone Powder Ash and WA=Wood Ash.

Table 2: Chemical Analysis of Cement Replacement Materials.

Elemental	% Composition						
oxides	AHA	BGSA	BPA	GHA	RHA	WA	C
Fe2O3	2.40	2.16	1.33	4.35	0.95	2.35	2.5
SiO2	40.46	33.36	3.16	54.03	67.30	3.80	20.70
Al2O3	5.50	1.75	6.39	39.81	4.90	28	5.75
CaO	0.84	10.91	28.68	1.70	1.36	10.53	64.0
SO3	0	6.40	0	0.09	2.80	0	2.75

Table 3: Price of Cement Utilized for 50kg of Binder Material.

Replacement material	% of replacement material	% of cement used	Price equivalent of cement
POFA	10	90	1305
RHA	30	70	1015
AHA	20	80	1160
BGSA	10	90	1305
GHA	10	90	1305
BPA	10	90	1305
WA	20	80	1160

Table 4: Workability and Density of Periwinkle Gravel Concrete.

Periwinkle gravel mix	Slump (mm)	Density (kg/m^2)
0:1	80	2508
1:3	70	2311
1:1	62	2164
3:1	45	2128
1:0	35	1944

value was less compared to other cement replacement materials as shown in tables 3. Due to its availability in large quantities, it is more promising and acceptable compared to other cement replacement materials.

The density and workability of periwinkle-gravel concrete reduced as a result of the increase in periwinkle content as shown in table 4. This reduction could be attributed to the texture and shape of the shell as rough textured angular and elongated aggregate; will require more water to effect workability than smooth rounded aggregate. Coefficient of uniformity for periwinkle shell was 1.14 while gravel was 1.1, both materials satisfied the required standard which ranges from 1-3. However; the periwinkle shell is also suitable for concrete production and can be used as partial replacement for river gravel in places where gravel is not in abundance.

Palm kernel shells will act as stone dust, sand, mineral filler and coarse aggregate for the production of asphalt concrete. At 0% palm kernel shell and 100% granite during mixing, the marshal stability was 14.14KN with a flow of 3.42mm while at 100% palm kernel shell the value was 7.78KN with a flow of 4.32mm as shown in fig 7. Marshal stability range for road surfaces, with vehicular capacity of 6000 per/day lies between 2-10KN; this implies that palm kernel shell up to 50% can be used as full replacement for coarse aggregate for light trafficked roads and 10% as partial replacement for coarse aggregate for heavy trafficked roads.

Crushed spent fire bricks can be comparable to the natural river sand because it falls under the zone ii gradation and can serve as partial replacement for sand in the production of good concrete. The compressive strength of partial replacement of concrete made from crushed spent firebricks was higher than the river sand aggregate concrete.

Results obtained from three different percentages of recycled aggregate contents (0%, 50% and 100%), showed that the compressive stress increased up to about 25% on increasing the quantity of coarse recycled aggregate up to 100%. It can be inferred that; concrete with more than 50% of recycled coarse aggregate should not be recommended for use on structural element where large deformation is expected due to its high shrinkage.

The introduction of recycled rubber tyres to concrete

Table 5: Compressive Strength (psi) of Recycled Tyres as partial Replacement for Coarse Aggregate.

Days	7	14	28
	Compressive strenght(psi)		
control	3600	4500	4600
10% modification	3000	3500	3650
15% modification	2500	2900	3150
20% modification	2000	2250	2550

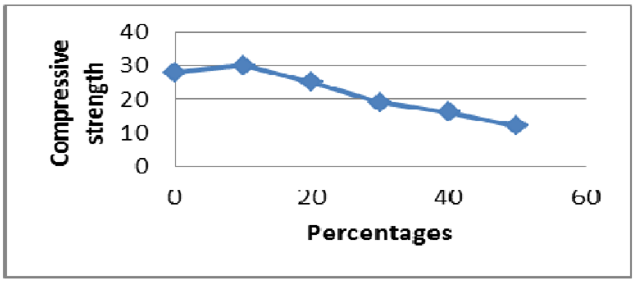

Figure 1: Compressive strength (kN/mm2)of concrete replacing cement with varying percentages of bone powder ash.

significantly decreased its workability. All the mixes made from recycled tyres had slumps less than 0.0508m which is unacceptable. Slump for 10% rubber content was 0.016m, for 15% was 0.013m and for 20% rubber content 0.0032m. This showed that, as the amount of rubber replacement material increases, the compressive strength of the concrete decreases as shown in table 5.

Upon examination of the broken cylindrical concrete with recycled tyre aggregate content, it was observed that the concrete broke around the rubber particle through the interfacial transition zone considered as the weakest zone in concrete. However, concrete containing shredded rubber particles is not recommended for structural use but can be used as light concrete for nonstructural purposes.

Based on the cost analysis of a research carried out in the Niger Delta region of Nigeria in the year 2002, results showed that the cost of 1m^3 of concrete made from conventional aggregate material compared with that made by substituting aggregate material with 25% of fine aggregate and 25% of coarse aggregate using sawdust and palm kernel shell; cost of construction can be reduced by 7% by replacing 25% of coarse aggregate with palm kernel shells. This conforms to results obtained from this research when palm kernel shell was used as partial replacement of aggregate.

5. Conclusion

Concrete is mostly used in both construction and building industries and the cost of concrete production is relatively high due to the manufacture of its main constituent. This research presents a comparative cost and strength analysis of cement and aggregate replacement material aimed at reducing the cost of concrete production. Tests

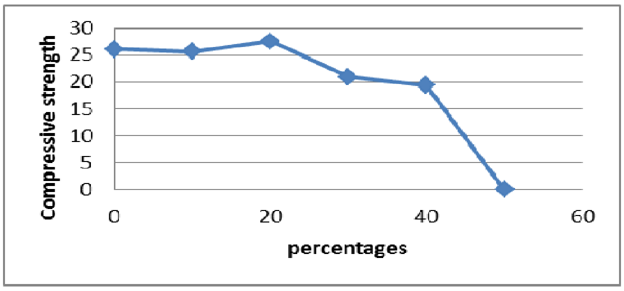

Figure 2: Compressive strength (kN/mm2) of concrete replacing cement with varying percentages of acha husk ash.

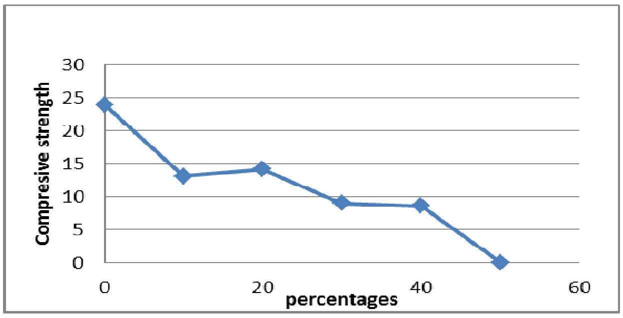

Figure 3: Compressive strength (kN/mm2) of concrete replacing cement with varying percentages of wood ash.

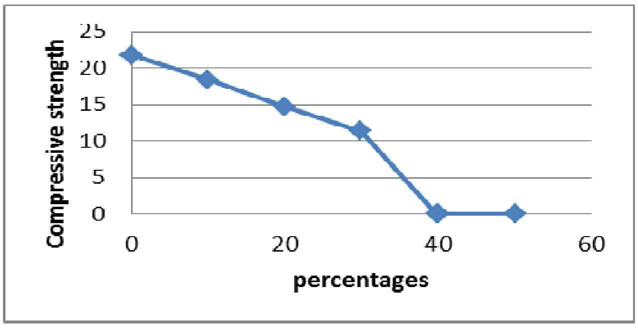

Figure 4: Compressive strength (kN/mm2) of concrete replacing cement with varying percentages of groundnut husk ash.

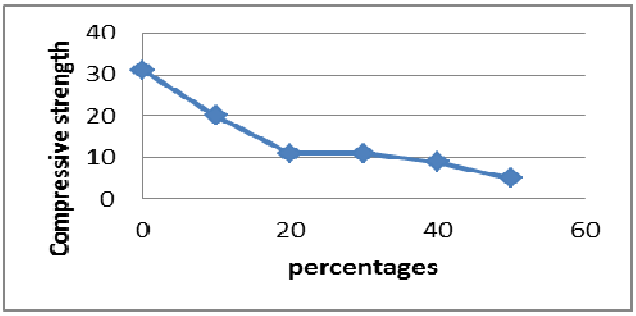

Figure 5: Compressive strength (kN/mm2) of concrete replacing cement with varying percentages of bambaranut shell ash.

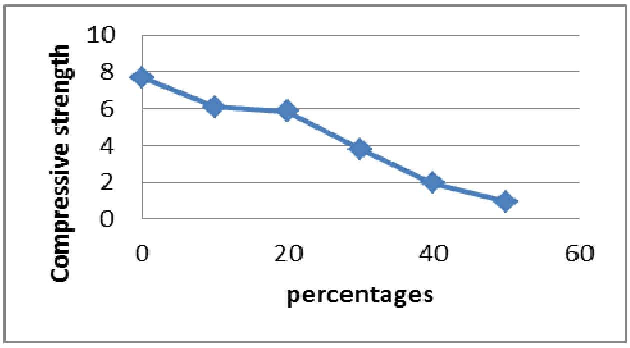

Figure 6: Compressive strength (kN/mm2) of concrete replacing cement with varying percentages of palmoil fuel ash.

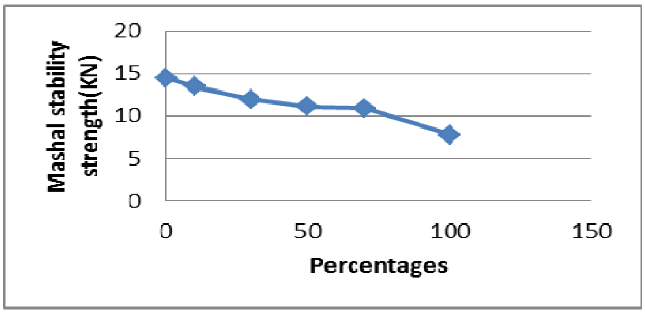

Figure 7: Marshal Stability Strength of Asphalt Concrete (KN).

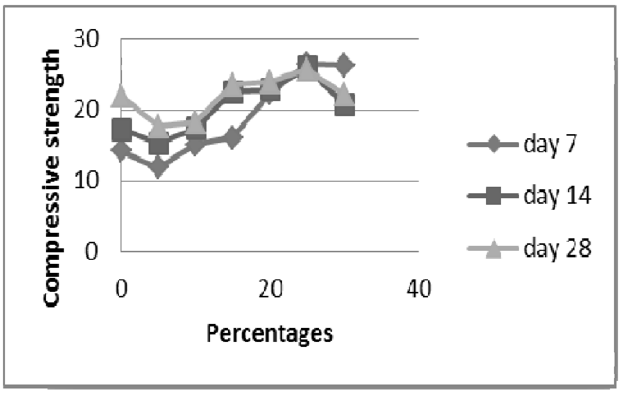

Figure 8: Compressive strength for crushed spent fire bricks (N/mm2).

were performed to compare the strength and cost analysis of various cement replacement materials (RHA,GHA, POFA,BPA,AHA and BGSA) and six aggregate replacement material (palm kernel shell, quarrydust, crushed spent fire bricks, periwinkle shell, recycled concrete and recycled tyres).

Results obtained from the strength and cost analysis of the various types of cement replacement materials showed that the bone powder ash had the highest compressive strength while, rice husks ash had the highest value of C2S. The rice husk ash best satisfies the cost requirement since its cost value was less compared to other cement replacement materials. Due to its availability in large quantities, it appears to be more promising and acceptable compared to other cement replacement materials. The coefficient of uniformity of the periwinkle shell meets the required standard, it can thus; be used as partial replacement for river gravel in places where gravel is not in abundance.

Due to the high demand for concrete in construction and building industries, the use of conventional aggregates has drastically reduced the natural stone deposits thereby; causing an ecological imbalance of the environment. Thus; the need to explore other suitable materials to substitute for the conventional cement and aggregate material should be encouraged.

Based on the findings of this research, the following contributions and recommendations would be found useful in building and construction management practices. Since the use of; cement and aggregate as partial replacement materials greatly enhanced the strength of concrete, they must be readily available in large quantities within the locality of the construction project in order to reduce the cost of construction. Planting of palm kernel trees should be encouraged because of its economical values. Further researches should be carried out on other cement and aggregate replacement materials in order to reduce the cost of concrete production.

References

1. Muga, H., Betz, K., Walker, J., Pranger, C., and Vidor, A. *Development of Appropriatand Sustainable Construction Materials.* Michigan Technological University Press, USA, 2005.
2. Awal, A.S and Hussin, M.W. Some Aspect of Durability Performance of Concrete Incoporating Palm oil fuel ash. Proceedings of *5th International conference on Structural failure, Durability and Retroffiting*, Singapore, 1997 pp 20-32.
3. Otunyo, A.W., Baami, N., and John, C.F. Combination of Palm Kernel Husk Ash PKHA and Free Lime (CaO) as an admix-ture in Concrete Production. *Nigerian Journal of Technology*, Vol. 30, No. 1, 2011, pp 64-71.
4. Jackson, N. and Dhir, K. *Civil Engineering Materials.* Macmillan Press Ltd, Houndsmills, London, 1996.
5. Kadiyal, L.R. and Lal, N.B. *Principles and Practices of Highway Engineering.* Khanna Publishers, New Delhi, 2009.
6. Tsytovich, N. *Soil Mechanics*, Mir Publishers, Moscow, 1981.
7. Manning, D.A. *Exploitation of Quarry Fines.* http://www.Mineralsolution.co.uk/mist. Accessed on February 20, 2004.