I.J.S.N., VOL. 4(1) 2013: 141-144 ISSN 2229 – 6441

INTERNATIONAL JOURNAL OF SCIENCE AND NATURE

www.scienceandnature.org

A COMPARATIVE EVALUATION OF THE APPLICATION OF AGRO-WASTE AS CONSTRUCTION MATERIAL

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ABSTRACT
This study evaluates the application of agro-waste as partial replacements for cement in construction activities. The properties of seven selected agro-wastes namely bambara ground shell ash (BGSA), acha husk ash (AHA), rice husk ash (RHA), groundnut husk ash (GHA), wood ash (WA), palm oil shell ash (POSA) and bone powder ash (BPA). The chemical ash analysis was done with the Bogue's model. A linear program calculates the equations governing the model for ease of complex computations. Results obtained revealed that bone ash (BA) has the most compressive strength and C_3S composition while rice husk is most economically viable. Local rice mills use firewood as source of heat and as such 100% of the rice husk from the mill is wasted. This reiterates the availability and abundance of rice husk ash. A concerted effort by stakeholders is needed to explore agro waste streams as durable raw materials in engineering works.

KEYWORDS: Agrobased, partial replacement, construction, chemical analysis, engineering work etc.

INTRODUCTION

Aggregates for concrete works are required to possess certain physical quality characteristics which include the ability to develop at the full strength of the cementing matrix (Concrete Engineering Handbook, 2010). Cement is a binder which sets and hardens and can bind other materials together. Portland cement is manufactured by heating calcium carbonate and clay or shale in a kiln at a temperature of 1300 – 1500 degrees Celsius. This process yields lime and dicalcium silicate (C_2S) and other inorganic oxides. The lime reacts with C_2S to form tricalcium silicate (C_3S) which undergoes phase transition (Barron, 2009). C_3S and C_2S are two important compounds responsible for strength. Together they constitute 70 to 80% of cement (Neville and Brooks, 2003).

Cement production consumes huge quantities of energy and emits large amounts of CO_2 which is a major cause of global warming. The use of concrete in road construction is associated with such environmental problems as gaseous emissions, visual pollution, traffic congestion, noise pollution, adverse health effects and water pollution (Bremner, 2001). Concrete generates about 7% of the total CO_2 generated worldwide hence contributing significantly to global green house gas problem. With increasing demand for raw materials for production, the non-renewable resources are dwindling by the day. Environmentally friendly construction materials are encouraged to rescue this situation.

In the third world, the most common and readily available materials that can be used to partially replace cement without huge economic implications are agro-based wastes. They are bambara ground shell ash (BGSA), acha husk ash (AHA), rice husk ash (RHA), groundnut husk ash (GHA), wood ash (WA), palm oil shell ash (POSA) bone powder ash (BPA), periwinkle shell ash, etc. Advantages derived from the use of agro-wastes as partial replacements for cement in construction are low capital cost per tone production when compared with cement, promotion of waste management at little cost, reduced pollution by these waste and increased economic base of peasant farmers when such wastes are sold, thereby encouraging more production, conservation of limestone deposits and a reduction in CO_2 emission (Joel, 2010).

Experiences have shown that POSA posseses good pozzolanic property and can be used as supplementary cementing material for the production of durable concrete (Safiuddin *et al.,* 2010). It produces high strength and shows good resistance to expansion due to sulphate attack and alkali silica reaction. RHA is rich in silica, highly porous and light weight, with a very high external surface area. It has absorbent and insulating properties (Ozeh, 2010); is a good super-pozzolan usable in making concrete mixes for production of high strength. In steel production, RHA, which possesses low thermal conductivity, high melting point, low bulk density and high porosity, make it an excellent insulator that can prevent rapid cooling in flat sheet production for automobile body panels (SCM, 2004). BGSA's use in concrete production has been recorded (Alabadan, 2005). Due to the variability of bone sources, there is inconsistency in the chemical composition of BPA (Aribisala and Bamisaye, 2006). WA contains calcium carbonate as its major component and could also be used as a major pozzolan in concrete (Rosenfeld and Henry, 2001). GHA, AHA and PSA could also be used as replacement for cement and can be an economic relief to developing countries (Alabadan *et al*., 2006).

Evaluation of the application of some processed agro-wastes wastes as construction materials as partial replacements for cement was considered by comparing the properties of the selected agro-wastes with natural resources. The environmental gains are discussed as well as the socio-economic benefits.

MATERIALS AND METHODS

Materials used include ordinary Portland cement (OPC), groundnout husk ash (BGSA), wood ash (WA), palm oil shell ash (POSA) bone powder ash (BPA),groundnut husk ash (GHA), conventional fine and coarse aggregates (sand and gravel) and water.

RHA was obtained from the combustion of rice husk at 438^{o}C. The product was ground and sieved through 212 micron BS sieve (Oyetola and Abdullahi, 2006). AHA was obtained by incineration between 650 and 700 ^{o}C to avoid formation of crystalline ash which is less reactive to lime. The resulting ash was ground in a ball mill to the required degree of fineness of cement (Dashan and Kamang, 1999). BGSA was obtained from burnt bambara groundnut shell at 500 ^{o}C in a furnace after threshing out the shell from the nut. The ash residue was sieved through 75 microm sieve after grinding (Joel, 2010). BPA was obtained from incineration of cattle bones in a furnace at a temperature of more than 900 ^{o}C. The residue was ground in a hammer mill to fine powder (Aribisala and Bamisaye, 2006). POSA was obtained by oven drying palm oil fuel ash in the oven at 110 ^{o}C to remove moisture. Ground ash was sieved through 45micron sieve and stored in airtight container and kept free from atmospheric humidity (Abdullahi *et al*., 2006 as cited by Ozeh, 2010). WA was powdered and sieved through 75 microns sieve.

The various samples were tested for 28 days compressive strength in accordance with BS1881:108:1983 (method for making test cubes from concrete) and BS1881:116:1984 (method for the determination of compressive strength of concrete cubes). Each specimen was placed with the cast faces in contact with the platens of the testing machine. The load was applied at a constant rate of stress within the range of 0.2 to 0.4 MPa/s, and the crushing strength reported to the nearest 0.5 MPa.

RESULTS AND DISCUSSION

The results of analyses are presented in Tables 1-4 and figures 1-4.

Variation in Compressive Strength

TABLE 1: Compressive Strength (KN/mm^2) of Concrete with Varying Percentages of Agro-waste Ash

Replacement ashes	Percent replacement of OPC					
	0	10	20	30	40	50
RHA	3.89	2.3	1.95	2.93	2.74	2.34
WA	23.96	13.09	14.13	9.02	8.59	0.0
POSA	7.70	6.10	5.84	3.81	1.95	0.96
GHA	21.78	18.4	14.67	11.40	0.0	0.0
BPA	28	30	25	19	16	12
AHA	26.10	25.60	27.60	20.90	19.40	0.0
BGSA	31	20	11	11	9	5

TABLE 2: Percentage Change in Strength of Agro-waste with respect to their various Control OPC

Control	OCS	Percentage Change in strength
100%C	70%C	-24.70
0%RHA, 3.89	30%RHA, 2.93	
100%C	80%C	-41.00
0%WA, 23.96	20%WA, 14.13	
100%C	90%C	-20.80
0%POSA, 7.70	10,POSA, 6.10	
100%C	90%C	-15.50
0%GHA	10% GHA, 18.40	
100%C	90%C	7.10
0%BPA, 28	10%BPA, 30	
100%C	80%C	5.70
0%AHA, 26.10	20% AHA, 27.60	
100%C	90%C	-35.50
0%BGSA, 31	10% BGSA, 20	

The optimum compressive strength of the replacement materials was achieved when cement was replaced with 10% BPA. The use of AHA at 20% led to the attainment of OCS. The use of BGSA to partially replace cement in concrete production exhibited a decrease in compressive strength with increase in BGSA content. Also compressive strength with GHA decreased with increase in GHA content. Also RHA and WA exhitied similar trends. Thus BPA exhibited the greatest appreciation in strength and is thus most suitable.

Ash Analysis

Table 3 shows the oxide composition of replacement ashes. The oxides (Fe_2O_3, SiO_2, Al_2O_3, CaO, SO_3) are the elemental constituents of a typical clinker and forms the bedrock of the Bogue's Model, which is an important analytical tool.

TABLE 3: Oxide Composition of Replacement Ashes % Composition

Oxides	AHA	BGSA	BPA	GHA	POSA	RHA	WA	C
Fe_2O_3	2.40	2.16	1.33	4.35	5.44	0.95	2.35	2.50
SiO_2	40.46	33.36	3.16	54.03	55.20	67.30	3.38	20.70
Al_2O_3	5.50	1.75	6.39	39.81	4.48	4.90	28.00	5.75
CaO	0.84	10.91	28.68	1.70	4.12	1.36	10.53	2.75
SO_3	0	6.40	0	0.09	2.25	2.80	0	2.75
Loss on ignition (LOI)	43.57	43.57	11.32	4.00	13.86	17.78	27.00	1.30

*C: chemical composition of the control OPC (clinker)

Table 3 shows that only GHA and RHA satisfied pozzolanic material requirement with the sum of SiO_2, Al_2O_3 and Fe_2O_3being greater than 70%. POSA, WA, AHA and BGSA had values lower than 70% and can be considered non-pozzolanic materials. Although BPA ia non-pozzolanic, its moderate CaO composition and low low SiO_2 components make it a valuable agro-waste.

Bogue's Model

The Bogue's equations provide a simple and convenient method to find out the final composition of a clinker. It is used to calculate the approximate proportions of the four main minerals in Portland cement clinker . These minerals are C_3S, C_2S, C_3A and C_4AF.

The Bogue's equations for potential composition are given as:

C_3S = $4.07(CaO) – 7.60 (SiO_2) – 6.72(Al_2O_3) – 1.43(Fe_2O_3) – 2.85(SO_3)$

C_2S = $2.87(SiO_2) – 0.753(C_3S)$

C_3A = $2.65(Al_2O_3) – 1.69(Fe_2O_3)$

C_4AF = $3.04(Fe_2O_3)$

Cement clinker is a combination of lime and silica and also lime with alumina and iron. Although Bogue's equation is limited in application, it is useful in the cement industry. The clinker analysis as extracted from Table 3 gives the following:

TABLE 4: Clinker Analysis

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
20.7	5.75	2.5	64	1.54	2.75	1.3

The optimum compressive strength for RHA is obtained at 30% replacement level (Table 2)

i.e. 70%C + 30%RHA

Thus the elemental oxides are computed thus:

SiO_2, 70%C	=	70H 20.7
	=	14.49
30%RHA	=	30H 67.30
	=	20.19
Adding up	=	34.68
Al_2O_3, 70%C	=	70H 5.75
	=	4.025
30%RHA	=	30H 4.90
	=	1.47
Adding up	=	5.49
Fe_2O_3, 70%C	=	70H 2.5
	=	1.75
30%RHA	=	30H 0.95
	=	0.29
Adding up	=	2.04
CaO,70%C	=	70H 64
	=	44.80
30%RHA	=	30H 1.36
	=	0.41
Adding up	=	45.21
SO_3, 70%	=	70H 2.75
	=	1.93
30%RHA	=	30H 2.80
	=	0.84
Adding up	=	2.77

Replacing these values in Bogue's equations yields (for RHA)

C_3S = 127.37

C_2S = 195.57

C_3A = 11.11

C_4AF = 6.20

Hence applying the analysis to other samples yields Table 5 which shows that only the replacement with BPA has calculated C_3S value greater than 50.7 recorded for OPC. The other ashes exhibited increased values in C_2S particularly RHA. C_3S and C_2S composition in cement play very crucial roles in strength gain by concrete (Neville and Brooks, 2003).

TABLE 5: Percentage Bogue Compound Composition of Main Compounds in the Various Cement replacement Materials

	RHA 30%	POSA 10%	WA 20%	GHA 10%	BPA 10%	AHA 10%	BGSA 10%	C
C_3S	-127.37	3.08	-35.86	-19.97	53.35	-26.23	23.90	50.70
C_2S	195.57	33.20	92.87	84.02	14.93	90.47	45.68	22.50
C_3A	11.11	8.10	22.86	19.73	11.37	10.91	10.02	8.60
C_4AF	6.20	10.18	7.50	8.18	7.24	7.54	7.50	9.40

Cost Analysis

Due to high demand for concrete in the construction industry, the use of conventional raw materials like aggregates and limestone has drastically depleted natural deposits thereby causing ecological degradation necessitating the exploration of suitable alternatives. The current cost of one 50kg bag of OPC is N1750, hence the calculated price of OPC utilized per tone of binder is shown in Table 6.

TABLE 6: Price of OPC Utilized per Tonne of Binder Material (Agro-waste Ash)

Replacement Material	% Replacement Material	% Cement Used	Price Equivalent of Cement per Tonne in Naira
POFA	10	90	32,004
RHA	30	70	24,892
AHA	20	80	28,448
BGSA	10	90	32,004
GHA	10	90	32,004
BPA	10	90	32,004
WA	20	80	28,448

RHA best satisfies the cost requirement. Rice is a staple food in Nigeria and is grown locally also, rice husk is readily available as it is generated by various mills. RHA is therefore economically viable compared with other agro-wastes.

CONCLUSION

The partial replacement for cement in concrete with agro-waste is aimed at the pursuance of Clean development Mechanism, conservation of resources as well as combating the environmental degradation associated with mining of silica and limestone. The study has shown that bone ash has the highest compressive strength and C3S while rice husk is the most economically viable. Proper utilization of agro-wastes should be given due attention in Nigerian economy.

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