A REVIEW OF PARTIAL REPLACEMENT OF CEMENT WITH SOME AGRO WASTES

Manasseh Joel
University of Agriculture,
Civil Engineering Department,
P.M.B.2373 Makurdi, Benue State.
e-mail:manassehjoel@yahoo.com.

ABSTRACT

The use of Acha husk ash (AHA), Bambara groundnut husk ash (BGHA), Bone powder ash (BPA), Groundnut husk ash (GHA), Rice husk ash (RHA), and Wood ash (WA) to partially replace cement as a binder was reviewed. Analysis of results, using oxide composition, compound composition obtained using Bogue's model, and results of test conducted in the laboratory, showed that only the replacement of cement with 10%BPA exhibited a convincing increase in compressive strength of 7.14% above that obtain with the use of cement. Decrease in compressive strength observed with other agro waste was attributed to increase in SiO_2 component and decrease in CaO component of cement-agro wastes mixtures. Incorporation of lime into the mixture is here by recommended for increase in strength.

Key words
Agro-wates, Cement, Partial, Replacement, Concrete.

INTRODUCTION

The high cost of cement, used as binder, in the production of mortar, sandcrete blocks, lancrete bricks and concrete has led to a search for alternative. In addition to cost, high energy demand and emission of CO_2, which is responsible for global warming, the depletion of lime stone deposits are disadvantages associated with cement production. According to Babu and Rao [1] about 7% CO_2 is released into the atmosphere during cement production, which has a negative influence on ecology and future of human being arising from global warming. Research on alternative to cement, has so far centred on the partial replacement of cement with different materials. In advanced countries, partial replacement of cement with pozzolans is well documented and recommended, [1, 2, 3]. Pozzolans as defined by [4] are siliceous material, which by itself possesses no cementitous properties but in processed form and finely divided form, react in the presence of water with lime, to form compounds of low solubility having cementitious properties. They are grouped into natural and artificial sources; clay and shale calcined to become active, volcanic tuff and pumicite are naturally occurring pozzolanas, whereas good blast furnace slag and fly ash are the artificial varieties. In advance countries, the use of fly ash, a residue obtained from the combustion of pulverized coal in partial replacement of cement is recommended within the range of 10-30% by weight of cement [4].

Mixtures of Portland cement and pozzolanic material is referred to as pozzolanic cements, such cement have the following advantages good resistance to chemical attack, low evolution of heat of hydration, economy, improvement of workability, reduction of bleeding and greater impermeability. Its disadvantages being, slower rate of strength development and increased shrinkage [5].

In the third world countries, the most common and readily available material that can be used to partially replace cement without economic implications are agro based wastes, notable ones are Acha husk ash (AHA), Bambara groundnut shell ash (BGSA), Bone powder ash (BPA), Groundnut husk ash (GHA), Rice husk ash (RHA) and Wood Ash (WA) [6] gave a list of additional agro waste material as Ashes from the burning of dried banana leaves, bagass, bamboo leaves, some timber species, sawdust and periwinkle shell ash (PSA).

Advantages to be derived from the use of agro waste in the partial replacement of cement as presented by [7, 8] are low capital cost per tonne production compared to cement, promotion of waste management at little cost, reduced pollution by these wastes and increased economy base of famers when such waste are sold, thereby encouraging more production, conservation of limestone deposits and a reduction in CO_2 emission.

MATERIALS AND METHODS

A brief description and sources of the agro wastes under review are summarized below:

Acha Husk Ash (AHA)

Acha husk from which AHA is obtained is the outer covering of the "Acha grain". The process of removal (threshing) is done manually using pestle and mortar. Acha is a member of small millet and is often known as "hungry rice". The crop is grown in plateau, Bauchi and in southern parts of Kaduna state of Nigeria. AHA is obtained by incinerating Acha husks within a temperature range of 650-700°C, to avoid formation of crystalline ash which is less reactive to lime. The resulting ash was grounded in a ball mill to the required degree of fineness of cement, [7]. Its oxide composition is as summarized in Table 1. AHA is a non pozzolanic material with a specific gravity value of 2.12. Its CaO component is less than that of cement.

Bambara Groundnut Shell Ash (BGSA)

Bambara groundnut shell ash is obtained from burnt bambara groundnut shell at temperatures of 500°C in a furnace, after threshing/separation of the shell from the nut using the threshing machine. The burnt ash was sieved through 75microns BS sieve after grinding. BGSA is available in large quantities in some northern states of Nigeria, namely, Sokoto, Kebbi, Kaduna, Borno and Yobe states. It is also available in the central states of Benue, Kogi, Nasarrawa, kwara to mention but a few. Oxide composition of the ash is as reflected in Table 1. BGSA is a non pozzolanic material.

Bone Powder Ash (BPA)

Bone powder ash was obtained from the incineration in a furnace at a temperature of more than 900°C of cattle bones. The bones were cleaned and sun-dried to reduce its oil content before incineration. The burnt bone was allowed to cool before it was ground in a hammer mill to fine powder [9]. Cattle bones are readily available in commercial quantities in various abattoirs that litter the cities and villages in Nigeria. Oxide composition of BPA as reported by [9] is as summarized in Table 1. It has a specific gravity of 2.58, it cannot be classified as a pozzolanic material as the sum of SiO_2, Al_2O_3 and Fe_2O_3 is less than 70%. The CaO content of BPA is less than that of cement.

Table. 1. Composition of Elemental oxides of the different Agro-wastes as presented by [7, 8, 9, 10, 11, 13, 14]

Elemental Oxides	Percentage Composition						
	AHA	BGSA	BPA	GHA	RHA	WA	C
ZnO	-	-	9.63	-	-	-	
CuO	-	-	10.98	-	-	-	
Fe_2O_3	2.40	2.16	1.33	4.35	0.95	2.34	2.50
MnO_2	-	-	0.46	0.10	-	-	
MgO	0.08	4.72	12.62	0.004	1.81	9.32	1.94
SiO_2	40.46	33.36	3.16	54.03	67.30	31.8	20.70
Al_2O_3	5.50	1.75	6.39	39.81	4.90	28	5.75
K_2O	0.24	16.18	7.43	0.17	-	10.38	
CaO	0.84	10.91	28.68	1.70	1.36	10.53	64.0
Na_2O	0.22	9.30	1.24	0.85	-	6.5	
P_4O_{10}	-	-	0.18	-	-	-	
SO_3	-	6.40	-	0.09	2.8	-	2.75
CO_3	-	6.02	6.70				
P_2O_5				1.44			
HCO_3		9.20					
LOI	43.57		11.32	4.0	17.78	27	1-3
Others			6.70				
$SR=SiO_2/(Al_2O_3+Fe_2O_3)$	5.12	8.53	0.41	1.22	11.50	1.05	2.40
$AR=Al_2O_3/Fe_2O_3$	2.29	0.81	4.80	9.15	5.16	11.97	2.44
$\sum SiO_2+Al_2O_3+Fe_2O_3$	48.36	37.27	10.88	98.19	73.15	62.14	29.46
$CaO:SiO_2$	0.02	0.33	9.08	0.03	0.02	0.033	3.13

AHA =Acha Husk Ash, BGSA =Bambara Groundnut Shell Ash, BPA =Bone powder Ash, GHA= Groundnut Husk Ash, RHA= Rice Husk Ash, WA= Wood Ash. AR= Alumina Ratio, SR = Silica Ratio, LOI = Loss on Ignition.

Groundnut Husk Ash (GHA)

Groundnut husk ash as reported by [10] was obtained from burning of dried groundnut shell or husk, at a temperature of 600°C to 700°C, after which the burnt husk/shell was ground into very fine powder using pestle and mortar (in the absence of ball mill) and made to pass through 212 microns BS sieve. The husk was obtained from groundnut an important cash crop in the tropics; cultivated in most of the central and northern states of Nigeria. GHA is a pozzolanic material with a specific gravity of 2.41, its oxide composition is as presented in Table 1.

Rice Husk Ash (RHA)

Rice husk ash is obtained from the combustion of rice husk a by product from rice milling operation, the husk accounts for 20-24% of the rough rice produced. The husk was burnt at a temperature of 438°C, before being grinded into fine particles. Using pestle and mortar (in the absence of ball mill) and made to pass through 212 micron BS sieve. In Nigeria, rice husk is produced in most northern and central states, were rice is grown, some of the states are Niger, Kaduna, Kano, Benue, Nasarawa, Kogi, Kwara etc. [11]. The Oxide composition of the RHA is as presented Tabel 1. RHA is a pozzolanic material, with a specific gravity of 2.13.

Wood Ash (WA)

Wood ash is obtained from the combustion of wood. It can be related to fly ash since fly ash is obtained from coal, which is a fossilized wood [12]. The wood ash used as reported by [13] was powdery, amorphous solid, sourced locally, from a bakery in Minna, The capital of Niger state of Nigeria. The wood ash was passed through the 75microns BS sieve. The chemical composition of the wood ash is as summarized in Table 1. It has a specific gravity of 2.13.

Bogue's model given as equations (1)-(4) was used in the calculation of the compound composition of cement and cement replaced with the different agro-wastes, due to difficulty in the direct determination of the principal compound.

$$C_3S = 4.07(CaO) - 7.60(SiO_2) - 6.72(Al_2O_3) - 1.48(Fe_2O_3) - 2.85(SO_3) \quad (1)$$

$$C_2S = 2.87(SiO_2)-0.754(C_3S) \quad (2)$$

$$C_3A = 2.65(Al_2O_3) - 1.69(Fe_2O_3) \quad (3)$$

$$C_4AF = 3.04(Fe_2O_3) \quad (4)$$

Calculations using Bogue's equations were based on the following assumptions:

I Concentration was a function of the weight, volume or percentage of each material in the combination of cement and any agro waste.

II The oxide composition of the percentage, of each material used is equivalent to the percentage of material used multiplied by the oxide composition of each constituent in the material. Example

(a).The CaO in 90 % Cement = 90 H 64.0 (for cement from Table 1) =57.6%

(b).The CaO in 10% AHA = 10 H 0.84 (for AHA from Table 1)= 0.084.

III In a mixture or combination of cement and any agro waste the oxide composition of the mixture is equal to sum of the proportion or the percentage of the oxide composition of each material in the mixture. Example, the CaO in a combination of 90% cement +10%AHA, = 57.6+0.084 = 57.684 as obtained in Table 2.

Compound composition of the different mixture as calculated based on assumption (I) – (III), is as presented in Table 2-7.

Since test on the suitability of the Agro-waste was carried out on blocks and concrete cubes, percentage decrease in strength was used as basis for evaluating the suitability of any combination of cement and the different Agro-wastes considered in the review.

Percentage decrease in strength equal strength achieved using cement replaced with the different percentages of the agro wastes, less strength achieved using only cement divided by strength achieved using only cement. Positive values indicate increase in strength while negative values represent decrease in strength. The output of the calculation for the different agro-wastes used in the study is as summarized in Tables 2-7.

RESULTS AND DISCUSSION

Analysis of Results

Results presented in Table 1, reveals that none of the agro-waste material satisfied the following requirement specified for cement, CaO: SiO_2 of 3.13, silica ratio (SR) and Alumina ratio (AR) of 1.7-3.5 and 2.44 respectively, a calcium oxide composition range of 60-67. Hence they cannot serve as substitute to cement, but can be used to partially replace cement. Only GHA and RHA satisfied, pozzolanic material requirement with the sum of SiO_2, Al_2O_3 and Fe_2O_3 being greater than 70%. WA, AHA and BGSA, had values lower than 70%, and can be considered as non pozzolanic material. BPA is also a non pozzolanic material with moderate CaO composition and lower SiO_2 component.

A careful analysis of the results in Tables 2-7, showed that only the replacement of cement with BPA has calculated C_3S values varying between 53.39 and 58.03, values greater than 50.7 obtained for ordinary Portland cement. The remaining agro wastes recorded lower values. Apart from the use of BPA which exhibited a decrease in C_2S with increase in BPA content, the remaining agro wastes exhibited increase in **C_2S** with increase agro waste content. It is worthy of note that C_3S and C_2S compound composition of cement plays critical role in strength gain as reported by [14].

The replacement of cement with AHA as reported by [7] increases initial and final setting times with the attainment of optimum concrete compressive strength when cement was replaced with 20% AHA. However, compressive strength of concrete made with AHA and cement combination as binder increased at 7 and 14 days, with a decline at 28 days. Unlike, cement which exhibited increase with days without a decline. The use of BGSA to partially replace cement in concrete production exhibit a decrease in compressive strength with increase in BGSA content. Optimum compressive strength was achieved when cement was replaced with 10% BGSA [8]. The use of BPA as reported by [9] increases initial and final setting time. Optimum compressive strength was achieved when cement was replaced with 10% BPA. The use of GHA to partially replace cement increases initial and final setting time. Compressive strength of concrete made with cement replaced with GHA decreased with increased in GHA content [10].

The use of cement replaced with rice husk ash in sandcrete block production, increased initial and final setting time, with RHA usage. The compressive strength of blocks decreased with increased in rice husk ash content, with the attainment of maximum compressive strength at a combination of 10% RHA and 90% cement [11]. Initial and final setting time increased with WA content. Compressive strength of concrete decreased with WA content, in cement partially replaced with WA in concrete production. Optimum concrete compressive strength was attained when cement was replaced with 20% WA [13].

Table. 2 : Compound Composition of Acha Husk Ash (AHA) Mixed with Cement(C). Using Bogue's Model

Elemental oxide composition	100% C 0%AHA	90% C 10%AHA	80% C 20%AHA	70% C 30%AHA	60% C 40%AHA	50 % C 50 % AHA
SiO_2	20.70	22.68	24.65	26.63	28.60	-
Al_2O_3	5.75	5.73	5.70	5.68	5.65	-
Fe_2O_3	2.50	2.49	2.48	2.47	2.46	-
CaO	64.0	57.68	51.37	45.05	38.40	-
SO_3	2.75	2.48	2.20	1.93	1.65	-
Compound composition						
C_3S	50.7	13.77	-25.72	-66.33	-107.41	-
C_2S	22.5	55.15	90.14	126.44	163.08	-
C_3A	8.6	10.98	10.91	10.89	10.82	-
C_4AF	9.4	7.57	7.54	7.51	7.48	-
28 days Compressive strength of concrete (N/mm^2)	26.10	25.60	27.60	20.90	19.40	-
Percentage decrease in strength. (%)	0	1.92	+5.75	-20	-26	-

Table 3 Compound Composition of Barbara nutshell Ash (BSA) Mixed with Cement(C). Using Bogue's Model

Elemental oxide composition	100%C 0%BSA	90%C 10%BSA	80%C 20%BSA	70%C 30%BSA	60%C 40%BSA	50 %C 50 % BSA
SiO_2	20.70	21.99	23.23	24.50	25.76	27.03
Al_2O_3	5.75	5.36	4.95	4.56	4.15	2.61
Fe_2O_3	2.50	2.47	2.43	2.40	2.36	2.33
CaO	64.0	58.69	53.38	48.07	42.76	37.46
SO_3	2.75	3.08	3.40	3.74	4.06	4.39
Compound composition						

C_3S	50.7	23.31	-5.86	-35.41	-64.70	-86.43
C_2S	22.5	45.54	71.10	97.01	122.72	142.75
C_3A	8.6	10.02	9.01	8.03	7.00	2.97
C_4AF	9.4	7.50	7.39	7.29	7.19	7.08
28 days Compressive strength of concrete. (N/mm^2)	31	20	11	11	9	5
Percentage decrease in strength. (%)	0	-35	-65	-65	-71	-84

Table .4 Compound Composition of Bone powder Ash (BPA) Mixed with Cement(C), Using Bogue's Model

Elemental oxide composition	100%C 0%BPA	90%C 10%BPA	80%C 20%BPA	70%C 30%BPA	60%C 40%BPA	50 %C 50 % BPA
SiO_2	20.70	18.95	17.20	15.44	13.68	11.93
Al_2O_3	5.75	5.82	5.88	5.95	6.01	4.93
Fe_2O_3	2.50	2.38	2.27	2.15	2.03	1.92
CaO	64.0	60.47	56.94	53.40	49.87	46.34
SO_3	2.75	2.48	2.20	1.93	1.65	1.38
Compound composition						
C_3S	50.7	52.39	51.88	51.33	50.91	58.03
C_2S	22.5	14.88	10.24	5.61	0.88	-9.52
C_3A	8.6	11.40	11.74	12.13	12.50	9.82
C_4AF	9.4	7.24	6.90	6.54	6.17	5.84
28 days Compressive strength of concrete (N/mm^2)	28	30	25	19	16	12
Percentage decrease in strength. (%)	0	+7.14	-11	-32	-43	-57

Table .5 Compound Composition of Groundnut husk Ash (GHA) Mixed with Cement. Using Bogue's Model

Elemental oxide composition	100%C 0%GHA	90%C 10%GHA	80%C 20%GHA	70%C 30%GHA	60%C 40%GHA	50 %C 50 % GHA
SiO_2	20.70	24.04	27.42	30.70	34.03	37.37
Al_2O_3	5.75	9.16	12.56	15.97	19.37	20.92
Fe_2O_3	2.50	2.68	2.87	3.06	3.24	3.43
CaO	64.0	57.77	51.54	45.31	39.08	32.85
SO_3	2.75	2.49	2.22	1.96	1.69	1.43
Compound composition						
C_3S	50.7	-20.20	-93.60	-166.33	-239.34	-300.00
C_2S	22.5	84.22	143.23	213.52	270.64	325.23
C_3A	8.6	19.74	28.43	37.15	45.86	49.64
C_4AF	9.4	8.15	8.73	9.30	9.85	10.43
28 days Compressive strength of concrete (N/mm^2)	21.78	18.40	14.67	11.40	-	-
Percentage decrease in strength. (%)	0	-16	-33	-48	-	-

Table 6. Compound Composition of Rice Husk Ash (RHA) Mixed with Cement(C). Using Bogue's Model

Elemental oxide composition	100%C 0%RHA	90%C 10%RHA	80%C 20%RHA	70%C 30%RHA	60%C 40%RHA	50 %C 50 % RHA
SiO_2	20.70	25.36	30.02	34.68	39.34	44.0
Al_2O_3	5.75	5.67	5.58	5.50	5.41	4.18
Fe_2O_3	2.50	2.35	2.19	2.04	1.88	1.73
CaO	64.0	57.74	51.47	45.21	38.94	32.68
SO_3	2.75	2.48	2.20	1.93	1.65	1.38
Compound composition						
C_3S	50.7	-6.39	-65.67	-125.04	-184.34	-235.98
C_2S	22.5	77.60	135.67	193.81	251.90	304.21
C_3A	8.6	11.06	11.086	11.14	11.16	7.78
C_4AF	9.4	7.13	6.66	6.19	5.72	5.26
28 days Compressive strength of 225 H 225 H 450mm sandcrete blocks. (N/mm^2)	3.89	2.3	1.95	2.93	2.74	2.34
Percentage decrease in strength. (%)	0	-40	-49	-23	-28	-38

Table 7. Compound Composition of Wood Ash(WA) Mixed with Cement(C). Using Bogue's Model

Elemental oxide composition	100%C 0%WA	90%C 10%WA	80%C 20%WA	70%C 30%WA	60%C 40%WA	50 %C 50 % WA
SiO_2	20.70	21.81	22.92	24.03	25.14	26.25
Al_2O_3	5.75	7.98	10.20	12.43	14.65	15.73
Fe_2O_3	2.50	2.48	2.46	2.45	2.43	2.42
CaO	64.0	58.65	53.31	47.96	42.61	37.27
SO_3	2.75	2.48	2.20	1.93	1.65	1.38
Compound composition						
C_3S	50.7	8.58	-35.69	-80.09	-124.40	-161.05
C_2S	22.5	56.13	92.69	129.35	165.95	196.77
C_3A	8.6	16.95	22.86	28.80	34.71	37.60
C_4AF	9.4	7.55	7.50	7.45	7.41	7.36
28 days Compressive strength of concrete. (N/mm^2)	23.96	13.09	14.13	9.02	8.59	-
Percentage decrease in strength. (%)	0	-45	-41	-62	-64	-

Discussion of Results

Decrease in strength with increase use of some of the agro-wastes to partially replace cement is due to, decrease in CaO component of cement replaced with agro-waste, as the contribution of CaO from the agro waste materials was not commensurate with the percentage reduction in CaO arising from the replacement of cement with agro waste. The use of most agro wastes, which resulted in the SiO_2 component being higher than the value obtained for cement, is another factor responsible for decrease in strength as it resulted in excess SiO_2 component in most combinations of cement and agro-wastes.

Decrease in C_3S with increase in agro-waste content in cement partially replaced with agro –waste material could be an indication of the level of deficiencies in C_3S of such combinations, with negative values indicating high level of deficiencies. The implication of these results is that deficiencies in C_3S, will lead to delay/slow rate of strength development, since early strength gain from the second day to the fourteenth day, as reported by [14] is dependent on C_3S component of cement. The quantity of hydrated lime liberated or evolved will also be low as C_3S hydration is known to liberate twice the quantity of lime liberated when compared with what is obtained during the hydration of C_2S. Lime liberated normally goes into further reaction that contributes to strength gain [14].

Compressive strength increase above the control point associated with the replacement of cement with 10% BPA may be due to the C_3S and C_2S values at this replacement level being close to the value obtained with the use of cement. The result is an indication that increase in C_3S component of a mixture of cement and agro waste up to a value of 52.39% and a decrease in C_2S to 14.88 against values of 22.5% obtained for cement will not result in strength reduction. Based on results obtained from the review, it can be deduced that any, combination of cement and agro waste with a C_3S/C_2S ratio of 3.52 and C_3S value of 52.39% will yield compressive strength result close to that of cement. The use of 10% and 20% AHA to partially replace cement resulted in strength increase above the control (use of only cement), the result however is not too convincing, as compressive strength of concrete made with cement replaced with 10% and 20 % AHA decreased at 28days, as compared with the use of only cement which exhibited strength increase at the same age. Decrease in strength with other agro-wastes is an indication that more lime is required in the replacement of cement with pozzolanic and non pozzolanic material due to low CaO content. It appears that lime liberated during the hydration of cement replaced with other agro-waste was not adequate enough to react completely with the siliceous component of the combinations, due to low C_3S component of most combinations of agro waste and cement. Additional lime can be provided through the use of calcium oxide rich material such as hydrated lime or carbide wastes to mention but a few.

Since it is the use of only 10% BPA that exhibited a convincing increase in strength, using this result and that obtained with the use of only cement, the following sets of conditions have been suggested for use as a guide in the replacement of cement with agro-waste, these conditions are: sum of C_3S and C_2S should lie between 67-73% ,the ratio of C_3S/C_2S should lie between 2.25 and 3.52, C_3S value should lie between 50.7 and 52.40, C_2S value should lie between 14.88 and 22.5, C_3A should lie between 8.60 and 11.40 and the C_4AF should lie between 7.24 and 9.40.

CONCLUSIONS

The following conclusions can be drawn from the study:

I.. Based on the review, GHA and RHA can be classified as pozzolanic materials, AHA, BPA, WA and BGSA can be classified as non pozzolanic materials.

II. Only the use of 10% BPA to replace cement has shown promising result in the replacement of cement with agro-wastes.

III. Addition of lime through the use of hydrated lime or carbide waste to cement and agro waste combination is recommended in the partial replacement of cement with agro waste, if strength equivalent or higher than that obtained with the use of only cement is to be achieved.

IV. The use of Bogue's model to calculate the compound composition of cement partially replace with any agro waste is suggested, in addition to the following conditions; C_3S of mixture of cement and agro waste should lie between 50.7% and 52.40%. C_2S should lie between 14.88 and 22.5%, C_3A should lie between 8.6% and 11.40%. C_4AF should lie between 7.24 and 9.4%.

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