Potential of Pulverized Bone as a Pozzolanic material

F. Falade, E. Ikponmwosa, C. Fapohunda

Abstract— This paper presents the results of a study on the potential use of pulverized bone (PB) as a pozzolanic material and supplementary cementing material in the production of concrete. Tests were conducted to determine the influence of pulverized bone on the consistency and the setting times of cement paste at different percentages of replacement from 0 to 100% at interval of 10%, using the Vicat Apparatus. 75mm cubes of cement/sand mortar were prepared from a mixture of cement and sand in the proportion of 1: 3 with water/cement ratio of 0.4 in order to determine its strength development pattern. The chemical composition of pulverized bone was also determined. The results showed that the incorporation of pulverized bone into cement paste resulted in low water demand to achieve the same consistency by as much as 30%. Also, the addition of pulverized bone into cement brought about delayed setting times of the paste indicating that the pulverised bone has a retarding effect on the paste. The results further indicate that pulverised bone could be used as a partial replacement of cement without damage to the strength provided that the level of replacement does not exceed 20%. Results of investigation showed that at up to 20% replacement of cement with pulverized bone, there was no significant difference in the 28-day strength of the specimens containing pulverised bone and the control specimens (without pulverised bone). From the results of this study, it can be concluded that pulverised bone has pozzolanic properties and it can be used as partial replacement of cement in concrete.

Index Terms— Cow bone, Consistency, Pozollans, Pulverized bone, Setting times.

1 Introduction

THE scarcity of building materials especially cement and its attendant high cost in Nigeria has made it difficult for low-income earners that constitute the majority of the population, to own their own houses, and also put in jeopardy the construction of civil engineering infrastructure that is needed for national development. The scarcity of cement has made it incumbent on researchers to find a cheaper, dependable and durable substitute material that can be used to partially replace the cement content for concrete production. One of the directions that researchers have beamed their searchlight on is the use of pozzolanic materials. Pozzolans are siliceous or siliceous and aluminous materials which in themselves do not possess any cementitious value but in finely divided form and in the presence of moisture will chemically react with calcium hydroxide (CH) to form a compound with cementitious value according to this general equation:

$$\text{Pozzolans} + \text{CH} \rightarrow \text{C-S-H} \qquad \ldots\ldots [1]$$

Calcium silicate hydrates (C-S-H) is the strength-forming products of cement hydration. Pozzolans can be classified as artificial if firing (or calcination) is required to induce pozzolanicity and natural if no calcination is required.

In recent times, by-products of industrial and agricultural activities often in the form of wastes have become the major source of pozzolanic materials which have been used as partial replacement of cement in the production of strong and durable concrete. Hussin and Abdullah [2] worked on palm oil fuel ash (POFA), and concluded that it has a beneficial effect on concrete provided the percentage replacement does not exceed 30%. Givi et al. [3] researched on rice husk ash (RHA). They showed that rice husk ash increased the setting times, improved workability, and increase the compressive and flexural strengths of concrete. Wilson and Ding [4] investigated the performance of fly ash in mortar and concrete. Their work indicated that the use of fly ash enhanced the workability and increased the setting times of cement mortar and concrete. Yilmaz [1] worked on silica fume and observed delayed setting times, increase in water demand and reduction in permeability with the use of silica fume. Falade [5] researched on saw dust ash (SDA). He concluded that the addition of sawdust ash decreased concrete strength and noted that the rate of gain of strength was more rapid in curing ages of 21 and 28 days, especially in the mixures with high percentage of SDA. Fapohunda [6] investigated the potential of granulated blast furnace slag to produce durable concrete. He concluded that the use of slag increased the ability of concrete to withstand chloride ingress, thus helping to produce durable concrete. Salau and Olonade [7] conducted a research into the pozzolanic potentials of cassava peel ash (CPA) on cement paste and mortar cube specimens. Their results showed that CPA retarded the rate of hydration reaction and setting times of cement paste; and at up to 15% replacement of cement with CPA, there were no significant different in the 90 days flexural and compressive strength when compared with the control sample (specimen without CPA).

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This paper reports on experimental investigation of the pozzolanic potential of pulverised bone as there is little information on the subject. Thus the objectives of this work are to:

i) Determine the quantity of cow bone that is available using Lagos State, Nigeria as a case study
ii) Determine the composition of pulverized bone
iii) Investigate the influence of pulverized bone on the consistency and the setting times of paste incorporating pulverized bone
iv) Assess the strength development of cement-sand mortar incorporating pulverized bone.

2 PROCEDURE FOR PAPER SUBMISSION

2.1 Materials

For this experiment, Ordinary Portland conforming to BS 12 [8] was used. The cow bones were obtained from Oko-Oba abattoir in Agege Local government of Lagos State, Nigeria. The bones were dried after they have been separated from all the muscles, flesh, tissues, intestines and fats. The dried bones were then milled or pulverized through a bone mill into powder, and the fraction passing through 150µm was later packaged in bags and stored in cool dry place. The availability of cow bone to meet the demand for its use was also investigated taking Lagos metropolis as a case study. The following tests were conducted on cement/pulverized bone paste, and cement/pulverized bone-sand mortar:

2.1.1 Chemical Composition of Pulverized Bone

In order to determine the constituents of pulverized bone, samples were subjected to analysis using the combination of Spectrophotometer, Atomic Absorption Spectrophotometer and Gravimetric methods at the Department of Chemistry, University of Lagos, Nigeria.

2.1.2 Consistency Tests on Cement/PB Paste

Water requirement to achieve the standard consistency of cement paste were carried out in accordance with BS 12 [8], using the Vicat probe and the Vicat needle apparatus, by partially replacing cement with pulverised bone at different cement replacement levels ranging between 10 and 100% at 10% intervals. Water demand for standard consistency was determined for each percentage replacement of cement with pulverized bone. The water demand for zero replacement of cement with pulverised bone serves as the control.

2.1.3 Setting Times of Cement/PB Paste

In order to assess the effect of pulverized bone on the setting times (initial and final) of cement paste, the water required to achieve the standard consistency of cement paste at zero percent pulverized bone replacement, measured by the water content that produced a paste that allows the Vicat plunger to sink to between 5 and 7mm from the bottom of the Vicat mould, determined in accordance with BS 12 [8], was used for this investigation. The water content was 30% (or w/c = 0.3). The setting times (initial and final) at the standard consistence of 30% at cement replacement levels of 10%, 20%, 30%, 40%, 50%, 60%, 70%, and 80% were then determined.

2.1.4 Strength Development of Cement/PB/Sand Mortar

75mm cubes of cement/sand mortar were prepared from a mixture of cement and sand in the proportions of 1: 3, and with water/cement ratio of 0.4. The specimens were prepared in accordance with BS 4551 [9]. Thereafter, the cement content of the mortar was progressively replaced with pulverised bone to the level of (80%) where the mixture could not set again because of high pulverized bone content. The replacement level was from 0 - 80% at the interval of 10%.

3 RESULTS AND DISCUSSIONS

The results of partial replacement of cement with pulverized bone in cement/sand mortar are presented below:

3.1 Availability of Cow Bones

The outcome of investigation into the availability of cow bones in the Lagos metropolis is presented in Tables 1 and 2

Table 1: Location of Source of Cows Bone in Lagos State, Nigeria

S/No	Name	Status	No of Cows slaughtered per day
1	Oko Oba, Agege	Abattoir	1500
2	Ashkpo, Ajegunle	Abattoir	100
3	Itire	Slaughter Slab	60
4	Matori	Slaughter Slab	50
5	Aswani	Slaughter Slab	15
6	Coker Aguda	Slaughter Slab	15
7	Ilaje	Slaughter Slab	20
8	Badagry	Slaughter Slab	25
9	Ikorodu	Slaughter Slab	80
10	Epe	Slaughter Slab	10
11	Ejigbo **	Slaughter Slab	-
12	Oke Aro **	Slaughter Slab	-
13	Goshen (Agege) **	Slaughter Slab	-
	Total Per day		**1875**

** Already established but yet to commence operation at the time of this investigation

Source: Adams [10]

The sites considered for this investigation are the officially approved and government controlled abattoirs and slaughter slabs.

Table 2: Availability of Cow Bone in Lagos State, NIGERIA

Number of cows slaughtered per day	1875
Average weight of a matured cow	400kg
Percentage of bone in a matured cow	20-30%
Total Weight of cows slaughter per day in Lagos	750,000kg
Percentage of bone generated as waste per day using the lower boundary of 20%	150,000kg
Annual weight of bone generated in Lagos State `	54,750,000kg (about 55000 tonnes)

Source: Adams [10]

The annual generation of cow bones is about 55000tonnes within the Lagos metropolis, excluding those generated unofficially by private individuals at weekend parties, rallies, religious festivals, sundry ceremonies, etc, which is definitely a multiple of the official figures. Based on the cow bones generation in Lagos metropolis, the annual national generation of cow bones can be conservatively put at about 5million tones. About two (2) million tonnes of the bones is used for animal feeds and other usage, the remaining three (3) million tonnes can be used for concrete production if found to be suitable, and this no doubt may result in reduction of cost of cement. The three (3) million tonnes is about 30% of the national cement production which Franklin [11] put at 9.5million tonnes (though about 19.5million tonnes of cement is consumed annually). This will also serve as way of recycling waste generated from cow meat consumption.

The result of the chemical analysis of pulverised bone carried out at the Department of Chemistry, University of Lagos is presented in Table 3. Also its effects on the physical and setting properties of cement paste is presented are Table 4. Figures 1, 2, and 3 are the results of consistency, setting times, and cube tests respectively.

3.2 Chemical Properties of Pulverized Bone (PB)

The results of chemical analysis on pulverised bone are presented in Table 3.

From Table 3, it is observed that that the chemical composition of pulverized bone is almost identical to that of the standard Ordinary Portland Cement. The fact that this similarity does not translate to ability to develop cementitious properties when later used in mortar cubes may be due to the presence of fat remnants in the pulverised bone, which seem to be inhibiting hydration. The following observations are also made:

- Pulverised bone has a high calcium content (over 70%), thus belonging to class C type of fly ash.
- The loss on ignition, a measure of the extent of carbonation and hydration of free lime and free magnesia due to atmospheric exposure, of pulverised bone is 1.14%. This value is within the limits of 3.0% set by BS 12 [8].

The alkalis (K_2O and Na_2O), with a combined percentage of 2.18% is low, and thus reduce the possibility of the destructive alkali-aggregate reaction (Neville, [12].

Table 3: Chemical Composition (%) of Ordinary Portland Cement (OPC) and Pulverized Bone

S/No.	Compound	OP Cement	Pulverized Bone
1	CaO	72. 26	70.87
2	SiO_2	6.39	7.03
3	Al_2O_3	0.88	0.91
4	Fe_2O_3	0.05	0.15
5	MnO	0.01	0.03
6	MgO	2.60	2.58
7	K_2O	0.39	0.51
8	Na_2O	1.58	1.67
9	SO_2	0.73	1.24
10	H_2O	0.62	0.75
11	CO_2	0.00	0.00
12	Loss of Ignition	0.98	1.14
13	Specific Gravity	2.92	2.22

3.3 Physical Properties of Cement Paste and Mortar Containing Pulverized Bone (PB)

The results of investigation on the influence of pulverised bone on some properties of cement are presented in Table 4. The parameters measured are: specific gravity, consistency, initial and final setting times and compressive strength. From the Table 4 above, the followings can further be observed:

3.3.1 The Specific Gravity

The specific gravity of the paste containing pulverised bone decreases gradually as the percentage of pulverised bone increased. Specific gravity decreased from 2.92 (that is, the control - the sample without pulverized bone) to 2.22 for samples without cement (that is 100% pulverised bone). This means that more volume of pulverised bone is required for equivalent weight of cement. Also the fact that the specific gravity of control is higher than paste with pulverised bone is an indication higher density. Lower density of paste with pulverised bone is an indication of a porous internal matrix compared with the control.

3.3.2 Water Demand for Consistency

The water requirement to produce a consistence paste, measured by the water content that produced a paste that allows the Vicat plunger to sink to between 5 and 7mm from the bottom of the Vicat mould, determined in accordance with BS 12 [8], reduces as the percentage of cement replacement with pulverized bone increased. That is, less amount of water was required to produce the same level of consistency, as pulverized bone content in the mix increased. This trend is shown in Figure 1.

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3.3.3 Setting Times of Cement Paste

The use of pulverized bone increased the setting times (initial and final) of cement paste as proportion of pulverised bone content increased up to 30% where the highest retardation of approximately 2 hours and $2^1/_2$ hours for initial and final setting times respectively occurred. Although the increase dropped beyond 30%, it can still be said to have a retarding influence up to 80% replacement when compared with the control. At 80% replacement, the paste did not set - a requirement for strength development. This can be seen in Figure 2. The fact that pulverized bone sets only in the presence of cement, to release calcium hydroxide (CH) during hydrolysis, is an indication of its pozzolanic traits.

TABLE 4. EFFECT OF PULVERIZED BONE (PB) ON PHYSICAL PROPERTIES AND SETTING TIMES OF OPC MORTAR

% PB	Specific Gravity	W/C Ratio for Standard Consistency	Setting Times		Retardation Ralative to Control (minutes)	
			Initial (min)	Final (min)	Initial	Final
0	2.92	0.30	114	229	0	0
10	2.90	0.28	150	295	36	66
20	2.84	0.28	195	330	81	101
30	2.74	0.27	230	380	116	151
40	2.65	0.26	193	350	79	121
50	2.56	0.24	185	335	71	106
60	2.48	0.23	160	295	46	66
70	0.40	0.23	145	252	31	23
80	0.39	0.22	131	240	17	11
90	0.29	0.21	-	-	-	-
100	0.22	0.20	-	-	-	-

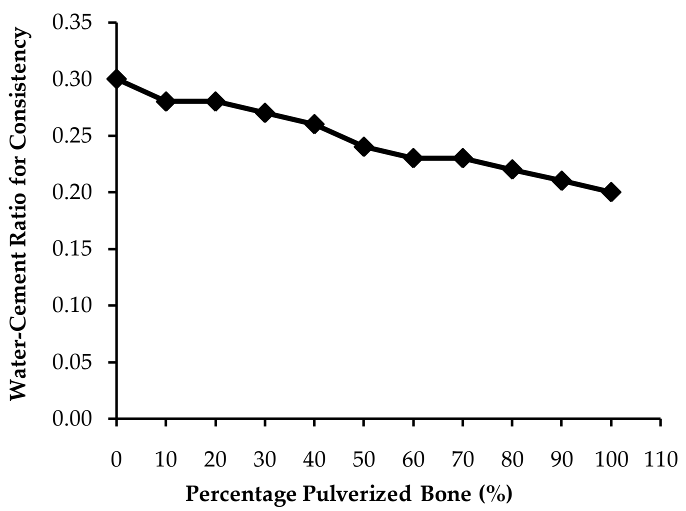

Fig. 1. Variation of Water-Cement Ratio in Cement-Pulverized Bone Paste for Constant Consistency

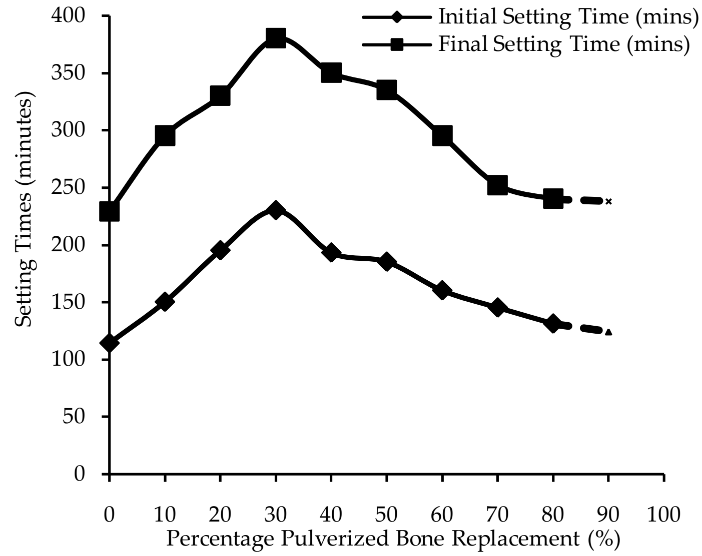

Fig. 2. Variation of Setting Times of Cement Paste With Different Pulverized Bone Content

3.3.4 Compressive Strength of Mortar

Figure 3 shows the variation of compressive strength of cement-pulverized bone mortar with time. The results indicate that pulverised bone on its own has no cementitious property as the cohesiveness of the mixture containing it weakens with increase in proportion of pulverised bone in mortar mixtures. At 80%, the setting time reduced but the corresponding compressive strength was very negligible while at 90% and 100% pulverized bone content, the mixture was no longer setting. This behaviour may be attributed to high pulverized bone content. For all the replacement levels, the strengths of the mixtures increased with age. However, the strength decreased as the percentage of pulverised bone increased. For example, at 28 days curing, the compressive strength increased from 1.10N/mm^2 at 80% cement replacement with PB to 35.23N/mm^2 at 0% cement replacement with PB. This behaviour of pulverised bone indicates that it exhibits pozzolanic characteristic. It is known that by adding pozzolanic material to cement mortar or concrete mix, the strength-forming pozzolanic reaction will only start when calcium hydroxide (CH) is released and pozzolan/CH interaction exist (Villar- Cocina et al., [13]). The more CH that is released, the more will be the pozzolanic activities, and the more will be the amount of the strength-forming calcium silicate hydrate (C-S-H) gel.

Although, the cubes containing pulverised bone have lower 28-day compressive strengths compare to the control, there is no significant difference between the 28-day compressive strength for cubes containing 20% percent pulverised bone and the control. Statistical analysis using the analysis of variance and the t- test were performed using t-distribution table to examine the significance of the differences in the 28-day compressive strengths between the control specimens and specimens containing different level of pulverised bone replacement (Appendix A). The results showed that provided the replacement of cement does not exceed 20%, there is no significant difference in the 28-day strength of the samples.

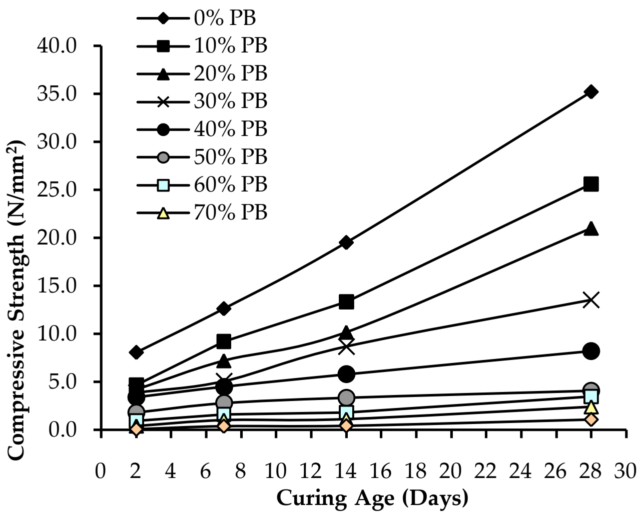

Fig. 3. Variation of Compressive Strength of Mortar With Different Replacement Levels of Pulverized Bone at differenr Curing Ages

4 Conclutions

From the foregoing, the following conclusions are made:

- There is a credible potential for pulverized bone to be used as a pozzolanic material in the production of concrete and its pozzolanic activities, measured by strength development increases with curing age.
- The pulverised bone does not contain dangerous oxides (K_2O and Na_2O) that have the potential to react destructively with other components of concrete, especially aggregates, to cause concrete deterioration.
- The incorporation of pulverised bone in cement-sand mortar progressively brought about reduction in the 28-day compressive strength when compared to the control sample. But a replacement of not more than 20% can be considered to have a prospect for use in concrete production, where the strength reduction is statistically insignificant when compared with the strength of the control specimens.
- The use of pulverised bone resulted in reduction in water required to produce pastes of the same consistency as the level of cement replacement by pulverised bone increased. The water content to produce standard consistence was 30% for the control sample, and this reduced progressively up to 20% as the pulverised bone content increased.
- The incorporation of pulverised bone in paste has a retarding effect, by implication, a delayed cement hydration and delayed early strength development.
- Pulverized bone can be classified as "natural pozzolan" because it does not require calcinations before it can develop pozzolanic characteristics.

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5 APPENDIX A. Statistical test of Significance of Difference in Strength

% PB	28-day Strength of 3 Cubes			Mean	S.D	t-test
1	32.80	27.60	30.29	30.23	2.6005	
10	26.00	23.90	22.03	23.98	1.9861	-5.453
20	18.70	19.10	21.15	19.65	1.3143	-5.702
30	13.10	14.20	13.35	13.55	0.5766	-18.32
40	8.62	8.01	8.00	8.21	0.3551	-26.05
50	4.00	3.98	4.32	4.10	0.1908	-37.31
60	3.62	3.45	3.43	3.50	0.1044	-9.954
70	2.34	2.42	2.44	2.40	0.0529	-36.01
80	1.10	1.09	1.11	1.10	0.01	-225.2

Assuming a 2-tailed confidence level of 2%, the critical value is ±6.965

The difference between the control and up to 20% replacement level is not to be considered significant.