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Evaluation of Physical and Mechanical Properties of Partially Replaced Bamboo Ash Cement Mortar

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----------*ABSTRACT*----------
The study investigates the evaluation of physical and mechanical properties of partially replaced bamboo ash cement mortar. Various tests such as fineness, soundness, drying shrinkage, air entrainment, water absorption, consistency, setting time, and chemical composition were carried out. The compressive strength as well as density of varying percentage of bamboo ash cement mortar cube of mixing ratio 1 : 6 and water cement ratio of 0.62 were examined and compared. A total of ninety (90) cement mortar cubes of size 50mm x 50mm x 50mm with different percentages by weight of bamboo ash to Portland cement in the order of 0%, 5%, 10%, 15%, 20% and 25% were cast. The cement mortar cubes were tested at the ages of 7, 14, 21, 28 and 56 days. The results showed that bamboo ash is not a good pozzolan with combined SiO_2, Al_2O_3 and Fe_2O_3 content of 37.68%. The soundness, consistency, water absorption, air porosity, initial and final setting times of cement paste increased with increase in bamboo ash content. The compressive strength and density of the cement mortar cubes increased as the days of curing increased and decreased with increasing ashes replacement. However, 10% of bamboo ash replacement was considered as optimum for the production of masonry mortar for building works.
KEYWORDS: bamboo ash, cement, chemical composition, compressive strength, mortar

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I. INTRODUCTION

Cement mortar consists of cement as binding material, sand in different proportions and water. Mortars are used for filling joints as a binder in stone and brick masonry, for plastering the surface of masonry to protect it from weather and to provide a pleasing and smooth finish. The strength of mortar depends on the cohesion of the cement paste, its adhesion to the aggregate particles and to a certain extent on the strength of the aggregates [18]. This therefore indicates the very importance of cement in mortar production. In Nigeria, the price of cement is increasing day by day. It is therefore important to find means of economizing the use of cement.

In recent years there has been increasing interest in utilizing agricultural waste ashes in mortar to improve some of the properties of the mortars [7]. If the waste can be reused and recycled, natural resources are used efficiently, waste is kept out of landfills and waste disposal costs are saved [3]. Utilization of the waste as a cement replacement material not only reduces the economic and environmental problems associated with the waste disposal but also reduces the carbon dioxide (CO_2) emissions during cement manufacture [17]. It was gathered that the production of every ton of cement emits carbon dioxide (CO_2) to the tune of about one ton. When expressing it in another way, it can be concluded that 7% of the world's carbon dioxide emission is attributable to Portland cement industry [20]. Therefore, partial replacement of cement with bamboo ash (BA) in mortar or concrete has two fold effect : (1) reducing the cement content in mortar and its negative economic and environmental impacts and (2) reducing the waste and the problems associated with them [7].

Several natural waste products such as pawpaw leaf ash, palm kernel shell ash, groundnut shell ash, banana leaf powder and cattle bone powder are already in use in mortar or concrete as mineral admixtures to improve mortar or concrete properties in fresh and / or hardened state [11, 12, 15, 21]. Another potential source is bamboo waste generated during the annual industrial processing of approximately 20million tons of bamboo for diverse applications including construction materials, bamboo furniture and even the high – technology industry [26, 27]. These wastes are either disposed of in landfills or burnt, ultimately harming the environment by polluting the air and occupation of useful lands. In addition, the biodegradation of bamboo, which is a natural lignocellulosic composite [9], emits methane, with an atmospheric heating effect of 72 times higher than that of CO_2 [13].

Studies about the use of bamboo leaf waste have been carried out by many researchers but no research is available on waste obtained from the whole of bamboo plants. Asha et al. [4] examined the effect of bamboo leaf ash (BLA) as cement replacement on compressive strength and durability characteristics of concrete. They found out that the compressive strength of the concrete decreases with increase in percentage content of BLA but recorded improvement in acid and chloride resistance at 10% replacement of cement with BLA. Therefore they

concluded that concrete with BLA should be used for civil Engineering works where durability is a major concern than high strength. Ademola and Buari [1] assessed the strength behaviour of bamboo leaf ash blended cement concrete in sulphates environment and concluded that Portland cement – bamboo leaf ash blended cement concrete could be used in Civil Engineering and building works in sulphate environment and where early strength is not a major requirement. Umoh and Odesola [25] investigated the characteristics of bamboo leaf ash blended cement paste and mortar. They concluded that the results of the physical properties of the pastes were within the requirements stipulated by relevant standards while that of the mortar cubes indicated that the compressive strength generally increased with curing age and that the mix containing 15% BLA by mass competes favourably with that of the reference mix at 28 days and above. Sara S. et al. [22] studied the assessment of bamboo culm ash (BCA) for use as an additive in concrete. They found out that the compressive strength of the concrete decreases with increase in percentage content of BCA while the initial and final setting time both increased with increasing BCA content. Therefore they concluded that BCA could be considered for applications in which the retarding of the setting time of the concrete is a higher priority than its strength.

Although all the research on either bamboo leaf ash or bamboo culm ash produced promising results, no study could be found on the use of the whole of bamboo ash as an admixture in mortar. Therefore, this study investigate the evaluation of physical and mechanical properties of partially replaced bamboo ash cement mortar with a view to establishing the suitability of bamboo ash blended cement for masonry work.

II. EXPERIMENTAL PROCEDURES

2.1 Mortar Materials

Materials used in the tests are ordinary Portland cement (Dangote Brand) whose properties conform to BS 12 [6], Bamboo Ash (BA), sharp sand (fine aggregate) and water. The mix proportion was 1 : 6 by weight (cement / BA : fine aggregate) with a water – cement ratio of 0.62. The proportions of cement to bamboo ash in the mortar were 100 : 0% as control, 95 : 5%, 90 : 10%, 85 : 15%, 80 : 20% and 75 : 25% respectively.

2.1.1 Preparation of Bamboo Ash (BA)

The bamboo poles used were gotten from the back of Timi Agbale Grammar School, Ede, Osun State of Nigeria. Only matured bamboo poles were used. The whole of bamboo poles were then burnt into ash by open burning. The idea of burning it in a furnace was dropped because it will be time – consuming and uneconomical for most people especially those at the rural areas. The whole of bamboo poles burnt were then grounded after cooling using mortal and pestle and the burnt ashes was sieved through British standard sieve of 75µm. The portion passing through the sieve would have the required degree of fineness of 63µm and below according to Kolawole and Mbachu [14] while the residue was thrown away.

2.2 Production of Mortar Cubes

The batching of the mortar materials was done by weight. Table 1 shows the batching information for mortar cube cast. The mixing was done on a dry, clean and hard surface. The required quantity of sand was measured and spread using a shovel to a reasonably large surface area. The cement in the mix was replaced by bamboo ash in proportions of 0%, 5%, 10%, 15%, 20% and 25% by mass of cement. The cement and bamboo ash were manually mixed in dry state and added to the already measured sand where the mixing continues until the whole mass becomes uniform in colour. Thereafter, a depression was made in the middle of the whole mass and the required quantity of water was added. Dry material from sides was placed on the edge of the depression containing water. It was done gradually till the water was completely absorbed by the dry mass. Care was taken not to let the water breach the banks and flow out. The wet mass of mortar was then worked with shovel until a homogenous mix was achieved. The fresh mixture was cast in cube moulds of size 50mm x 50mm x 50mm in two layers and each layer was tamped for 25 times. Immediately after the casting, the mortar cubes were covered with a polyethylene sheet for 24 hours to avoid escape of moisture. For each of the cement / ash proportions, three mortar cubes were cast and therefore, a total of ninety (90) cubes were produced for testing. At the end of 24 hours, the mortar cubes were removed from the moulds and later kept in storage curing tank measuring 2.0m x 6.0m filled with tap water only for periods of 7, 14, 21, 28 and 56 days respectively.

III. TESTING

3.1 Chemical Composition of Bamboo Ash (BA)

The chemical composition of bamboo ash (BA) was carried out at Hegada Scientific Services Limited, Samoda, Ibadan in Oyo State. The results were shown in Table 2 and compare it with that of ordinary Portland cement (OPC).

3.2 Density

Before the compressive strength test was carried out, the mass of the mortar cube specimens were taken to determine the density of the mortar cubes. The density of the mortar cubes were then obtained from the mass and volume of the mortar cube which is evaluated as :

$$Density = \frac{M}{V} \quad -------- \quad (1)$$

Where:

M = Mass of the Mortar Cube,
V = Volume of the Mortar Cube.

3.3 Compressive Strength

The compressive strengths of the mortar cubes were determined after 7, 14, 21, 28 and 56 days of curing by testing three mortar cubes from each mix and calculating the average of the three mortar cubes.

3.4 Determination of Air Entrainment

Air entrainment test of mortar present the percentage of air content both entrapped and entrained in the mortar. It is very important in the mortar that is exposed into a thaw condition to prevent bleedings and also use to reduce unit weight beyond what the aggregate can provide for a light weight concrete likewise to ensure that cement does not show any appreciable subsequent expansion.

The required quantity of cement and sand were measured and thoroughly mixed together until a uniform mixture was attained. The required quantity of water was measured and added gradually to the mix before a specific flow was observed. The prepared mix was put into the air entrainment (i.e. pressure box) using scoop and then compacted in three layers with each layer having 50 blows. The equipment was closed and well clamped. But water has allowed in through the opening at the top until it got to the zero level. Then air was pumped into the mortar to an extent that the level of the water in the equipment stopped reducing. The reading at this level was obtained. The process was then repeated with 5%, 10%, 15%, 20% and 25% replacement of the cement with bamboo culm ash.

3.5 Determination of Water Absorption

Water absorption test was determined at 28 days only. The method adopted was that postulated by [16] in which the mortar cubes were dried in an oven at 110^{o}C for 24 hours and the mass taken was recorded as dry mass (M_d). The mortar cubes were then boiled in water for 2 hours and kept for another 24 hours in the same warm water for the water to penetrate the pores. At the end of 24 hours, the mortar cubes were taken out from the warm water and the mass taken was recorded as wet mass (M_w). Percentage of water absorption was calculated as follows:

$$\%\ of\ Water\ Absorption = \left(\frac{M_w - M_d}{M_w} \right) x\ 100 \quad ------ \quad (2)$$

Where:

M_w = Dry mass of Mortar Cube,
M_d = Wet mass of Mortar Cube.

3.6 Determination of Drying Shrinkage

Shrinkage is caused by loss of water by evaporation or hydration of cement and also by carbonation, the linear strain of bamboo ash is compared to that of cement in mortar production for strength evaluation. 115.73g of cement and 694.38g of sand were weighed and used as trial mixes. The required quantity of water was measured and added gradually to the mix before a specific flow was observed. The prepared mix was then put in the shrinkage mould and tampered in layers until it was well compacted. Thereafter, it was weighed, oven dried for seven days and the shrinkage and weight for each day was recorded.

The process was then repeated for 5%, 10%, 15%, 20% and 25% replacement of cement with bamboo ash. It should be noted that three moulds were used for each percentage replacement.

IV. TEST RESULTS AND DISCUSSIONS

4.1 Chemical Composition of Bamboo Ash (BA)

Table 2 shows the oxide composition of BA. The results showed that BA has combined percentage of (SiO_2 + Al_2O_3 + Fe_2O_3) of 37.68% which is much less than 70%, indicating that the sample is not a good pozzolanic materials in accordance with the requirements in ASTM C618 [5]. The CaO content (22.02%) in BA also shows that it has some self cementing properties. The oxide composition of BA also indicated a high content of K_2O (16.01%) and Na_2O (22.11%) which may be a source of disruption in cement mortar paste.

4.2 Physical Properties of Bamboo Ash

The physical properties of bamboo ash blended cement are presented in Table 3. The fineness, expressed as % retained on 75μm sieve, range from 22.64% for 0% BA content to 20.70% for 25% BA content respectively. It shows that the blended cement is finer in particle sizes than the control and that the higher the

quantity of BA in the blend, the lower the residue retained on the sieve [25]. However, the quantity of ash retained at each blended level was below the maximum percentage of 34% as recommended by [5].

The soundness of the blended cement paste shown in Table 3 ranges between 0.80mm and 1.20mm for replacement levels of 0% to 25%. These values are less than the 10mm limiting value recommended [19]. Hence, the cements do not show any appreciable change in volume after setting.

Table 3 also showed that the consistency of the bamboo ash blended cement paste increases from 31.2% to 46.4% for replacement levels of 0% to 25% bamboo ash. The water required for a standard consistency was noted to increase as the bamboo ash content increases. This can be attributed to the finer particle sizes of blended cement as much water is required for proper lubrication [25].

The initial and final setting time of bamboo ash blended cement paste were shown in Table 3. The results showed that the setting times of bamboo ash cement mortar paste increased with increase in BA content. This behaviour may be due to the presence of potassium oxide (K_2O) which hinders complete combination of lime and causes setting anomalies or negative effect on setting [24]. It may also be due to the possibility of formation of magnesium silicate ($MgSiO_3$) which is known to be a retarder thereby causing delay in the setting time of cement [23].

4.3 Density

The results of the density of the bamboo ash blended cement mortar cubes are shown in Fig. 1. It shows that the density decreases as the percentage of bamboo ash content increases and increases with increased in age of curing. The decrease in density with increase in bamboo ash replacement could be ascribed to the fact that bamboo ash is lighter than cement in the mix, hence there is a decrease in the mass of the mortar cubes without a change in the volume leading to a decrease in the density of the mortar cube [25]. This confirms a similar assertion [2] that increasing natural fiber (which is lighter than cement) content in composite materials, decreases the density of the composite.

4.4 Compressive Strength

The results of the compressive strength of bamboo ash blended cement mortar cubes are shown in Fig. 2. It shows that compressive strength increases with increased in age of curing and decreases as the percentage of bamboo ash increases. The increase in strength with age of curing is due to hydration of cement and pozzolanic reaction of bamboo ash. The decrease in strength with increase in bamboo ash replacement could be due to the reaction mechanism of bamboo ash, in which dilution of cement and slower strength development from the pozzolanic reaction would be responsible for the reduction in strength [10].

4.5 Air Entrainment

The results of the air entrainment of the bamboo ash blended cement is shown in Table 4. The Results showed that the porosity increases as the quantity of bamboo ash content increases. The blended mortar cubes were observed to have higher porosity values than that of the control. This phenomenon could be attributed to delay in the release of calcium hydroxide, $Ca(OH)_2$ during cement hydration which would have led to secondary formation of Calcium Silicate Hydrate, CSH, through the pozzolanic reaction of the bamboo ash and calcium hydroxide [25].

4.6 Water Absorption

The water absorption of the bamboo ash blended cement mortar cube presented in Table 5, indicated that the water absorbed by the mortar cube increases as the amount of bamboo ash content increases. The lowest value of 2.10% was obtained with the mix containing 0% bamboo ash while the highest value of 7.20% was obtained for mix containing 25% bamboo ash. This phenomenon could be as a result of the reduction of cement content resulting in less quantity for hydration [25].

4.7 Drying Shrinkage

The drying shrinkage of the bamboo ash blended cement mortar cube shown in Table 6, indicated that the drying shrinkage increases as the quantity of bamboo ash content increases. The lowest value of 0.4% was obtained for mix containing 0% bamboo ash while the highest value of 5.5% was obtained for mix containing 15% bamboo ash. The shrinkage of bamboo ash blended cement mortar cubes at replacement levels from 20% and above decreased with increase in bamboo ash content. The decrease in shrinkage may be due to high porosity of bamboo ash particles which absorbed more water than cement, leading to reduced shrinkage.

V. TABLES AND FIGURES

Table 1 : Batching Information For Mortar Cubes

Percentage of BCA	BCA (g)	Cement (g)	Sand (g)	Water (g)	Water / Cement Ratio
0	0	462.90	2777.40	287.00	0.62
5	23.15	439.75	2777.40	287.00	0.62
10	46.29	416.61	2777.40	287.00	0.62
15	69.44	393.46	2777.40	287.00	0.62
20	92.58	370.32	2777.40	287.00	0.62
25	115.73	347.17	2777.40	287.00	0.62

Table 2 : Chemical Composition of Bamboo Ash (BA)

Oxide	Percentage Composition (%)			
	Sample 1	Sample 2	Average	OPC (BS 12 Ranges)
SiO_2	21.12	21.16	21.14	17 – 25
Fe_2O_3	16.48	16.44	16.46	0.5 – 6.0
Al_2O_3	0.08	0.07	0.08	3 – 8
CaO	22.02	22.24	22.13	60 – 67
MgO	22.72	22.54	22.63	0.1 – 4.0
SO_3	0.15	0.16	0.16	1.0 – 2.0
PbO	0.06	0.08	0.07	
CuO	0.23	0.25	0.24	
Na_2O	22.11	22.18	22.15	
K_2O	16.01	16.26	16.14	
LOI	0.03	0.04	0.04	

Table 3 : Physical Properties of Bamboo Ash Blended Cement Paste

Physical Properties	Bamboo Ash Replacement (%)					
	0	5	10	15	20	25
Fineness (% Residue on 75µm Sieve)	22.64	22.13	21.69	21.24	21.07	20.70
Soundness (mm)	0.80	0.80	0.90	1.00	1.20	1.20
Consistency (%)	31.2	34.6	36.0	39.8	44.0	46.4
Initial Setting Time (mm)	120	145	185	195	230	265
Final Setting Time (mm)	162	184	198	222	285	450

Table 4 : Air Entrainment Result

BA, %	0	5	10	15	20	25
Void, %	2.2	4.3	5.1	6.2	6.9	7.8

Table 5 : Water Absorption Result

Bamboo Ash, %	0	5	10	15	20	25
Water Absorption, %	2.10	4.23	5.33	6.20	6.43	7.20

Table 6 : Drying Shrinkage Result

Bamboo Ash, %	0	5	10	15	20	25
Shrinkage, %	0.4	1.3	4.2	5.5	4.3	3.8

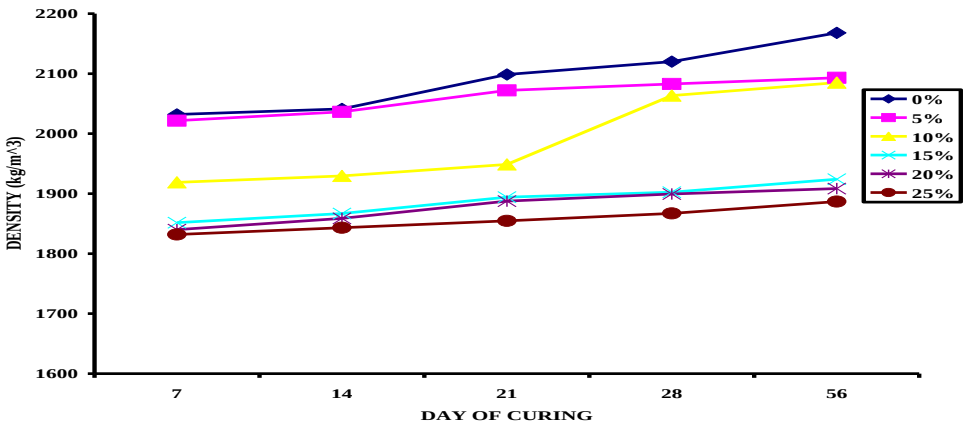

Figure 1 : Density of Bamboo Ash Blended Cement Mortar Cubes at Various Curing Days

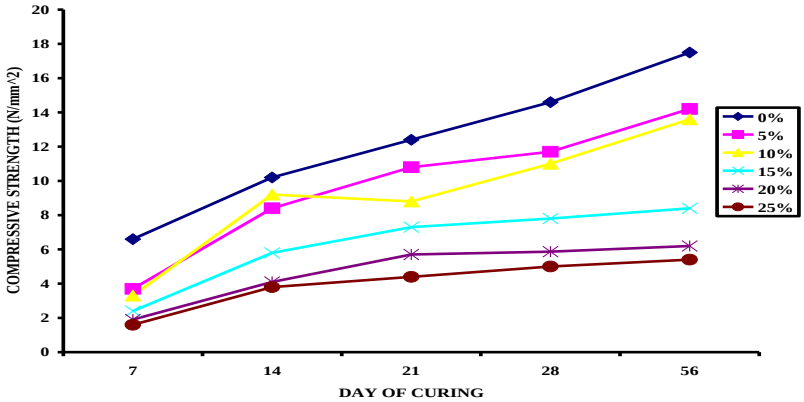

Figure 2 : Compressive Strength of Bamboo Ash Blended Cement Mortar Cubes at Various Curing Days

VI. CONCLUSION

From the results of the various tests carried out, the following conclusions can be drawn:

1. The bamboo ash is not suitable material for use as a pozzolan, since it does not satisfied the requirement for such a material by having a combined (SiO_2 + Al_2O_3 + Fe_2O_3) of less than 70%.
2. The bamboo ash which is lighter than cement and which occupies a greater volume for the same mass of cement requires additional water in the mix as the quantity of bamboo ash content increases in order to attain to a paste of standard consistency.
3. The initial and final setting times of the pastes varies between 120 – 265 minutes and 162 – 450 minutes respectively.
4. The compressive strength of bamboo ash blended cement mortar cubes increases with increase in days of curing and decreases with increase in percentage of bamboo ash. By increasing the percentage of bamboo ash from 5% to 25%, the 7 day compressive strength of mortar cubes decreased by 43.9% to 76% and the 56 day compressive strength of mortar cubes decreased by 20% to 70% compared to controls with 0% bamboo ash.
5. The density of bamboo ash blended cement mortar cubes decreases with increase in percentage of bamboo ash content and increases with increase in days of curing.

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