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Evaluation of the suitability of plantain peel ash as a secondary cementitious material/ filler in mortar

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Abstract

The possibility of using Plantain Peel Ash (PPA) as a cementitious or filler material in partial replacement of cement for mortar and concrete was investigated in this research work. Plantain peels were collected in Idah in Kogi state and carbonated in the open air to reduce the carbon content after which it was calcined in a muffled furnace at 600°C for 3 hours. Samples were taken for oxide composition using XRF analysis. Ordinary Portland cement was partially replaced with PPA at 0, 5, 15, 20 and 25% replacement levels and the OPC-PPA mix used as binder material to produce mortar cubes at 0.5% Water to binder ratio and binder – aggregates ratio of 1:6, which were cured for 7, 14 and 28 days respectively and tested for compressive strength. Durability of the PPA blended mortar was evaluated using water absorption, Sorptivity and apparent porosity tests. The result shows that while specific gravity decreased with increasing percentage replacement from 3.1 to 1.2 for 0 to 25% PPA replacement respectively, standard consistency and setting times increased with increasing percentage replacement. The oxide composition of PPA gives a combined SiO_2+Al_2O_3+Fe_2O_3 of 22.44%, which is less than the 50% required for pozzolanas. The compressive strength at 7, 14 and 28 days curing all increased with curing age but decreased as the percentage of ash increases, with only the mortar with 0% ash meeting the strength requirement for a class M mortar; and while the sorptivity increases with curing age and percentage replacement, water absorption and apparent porosity decreases with age but increases with percentage replacement. However, PPA blended mortars showed higher performance in acidic curing environment as compared to normal OPC mortars. It can be concluded on the basis of this research that while PPA does not meet the requirement of ASTM C618 for pozzolanas, it can be used as a filler material in concrete and mortar at up to 10% replacement of OPC to increase concrete durability when in acidic environment.

Keywords: Plantain Peel Ash; Oxide composition; Compressive strength; Durability; Acidic Environment; Mortar

1. Introduction

Sustainable development of the cement and concrete industry requires the utilization of construction materials that are readily and cheaply available for use in housing, road construction and other applications [1]. At present, for a variety of reasons, the concrete construction industry is not sustainable. Firstly, it consumes huge quantities of virgin materials that are non-replenishable. These materials include limestone, gypsum, aggregates, etc.; the high demand for housing and other applications has ensured continued use of these products. Secondly, the production of cement, the major binder in concrete and other applications, contributes greenhouse gases to the environment, and is thus implicated in global warming and climate change. Research by [2] indicates that the production of cement contributes 7% to the global CO_2 emissions. Other environmental effects, according to [3] include gaseous emissions, visual pollution, traffic congestion, noise pollution, adverse health effects and water pollution. Thirdly, the rising cost of cement has a profound

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effect on the overall cost of construction. Fourthly, many concrete structures suffer from lack of durability and thus do not live out their design lives, which may also lead to increased cost as well as waste the natural resources. Thus, finding practical recycled products that could substitute wholly or partially for cement will be desirable for sustainable development.

A material to be used in partial or full replacement of cement should not only be seen to possess cementitious properties, but should also solve the aforementioned problems. This material(s) should also be readily and cheaply available in abundance [4]. Materials that fulfill these specifications are referred to as pozzolana. By definition, a pozzolana is a siliceous or aluminous material that in itself is not cementitious but will in the presence of moisture, react with lime to form products that are similar to those formed during the hydration of cement. These materials can be natural or artificial in nature.

The use of industrial and agriculture-based wastes as pozzolana or as supplementary cementitious materials (SCMs)/ fillers in concrete production is becoming popular and attracting attention of many researchers [5]. Pozzolanic materials have long demonstrated their effectiveness in producing high performance concrete. Artificial pozzolanas such as rice husk ash have gained acceptance as supplementary cementing materials in many parts of the world [6]. In recent times, many waste materials like fly ash, periwinkle shell ash, and ashes produced from various agricultural wastes such as palm oil waste, rice husk ash, corncob ash, millet husk ash, groundnut husk ash, etc. have been tried as pozzolanas or secondary cementitious materials and have been successfully used in partial replacement of cement in concrete and mortar [7 - 10]. These supplementary cementing materials play an important role when added to Portland cement because they usually alter the pore structure of concrete to reduce its permeability, thus increasing its resistance to water penetration and water related deterioration such as reinforcement corrosion, sulphate and acid attack. [6]

Preliminary investigation carried out by [11] shows that Soybeans Husk Ash (another Agricultural based material) possesses pozzolanic properties and thus has the potential for use in concrete works. This research seeks to investigate another material – plantain peel Ash (PPA) with the aim of determining its potential for use as a pozzolanic or filler material by using it in partial replacement of cement, as well as investigate its effect on the properties of concrete and mortar.

2. Methodology

The methodology for this research work was divided into two parts. In the first part, Plantain peels were collected in Idah in Kogi state and burnt in the open air to reduce the carbon content after which it was calcined in a muffled furnace at 600^{o}C for 3 hours and sieved through a BS sieve of size 75μm to obtain ash of required fineness, and samples taken for oxide composition test using XRD analysis. The PPA was used to replace Ordinary Portland cement at 0, 5, 15, 20 and 25% respectively, and each PPA- OPC mix used to make 70.6 cubic meters mortar cubes, which were cured for 7, 14 and 28 days respectively in water and acidic environment and tested for compressive strength at the end of each curing period.

The second part involves Durability studies of the PPA blended mortar, which was evaluated using water absorption, Sorptivity and apparent porosity tests. The methods recommended by [12 and 13] were used in determining the water absorption, Sorptivity and apparent porosity of the 70.6 x 70.6 x 70.6 mm^3 mortar cubes for each percentage replacement at 7, 14 and 28 days curing respectively.

3. Results and discussion

3.1. Preliminary tests on Materials

The result of the materials testing is presented in table 1 and fig. 1 respectively.

The result shows that while the specific gravity decreases with the increase in quantity of PPA in the mix, the setting times and consistency increases with percentage replacement; the implication being that the addition of PPA to concrete increases the water demand and retards the setting times.

Table 1 Materials Characterization

Binder material	Quantity measured		
	Specific gravity	**Standard consistency**	**Setting times (Mins) Initial (Final)**
OPC	3.1	32.5	115 (185)
95%OPC-5%PPA	2.69	35.0	130 (200)
90%OPC-10%PPA	2.20	36.3	140 (210)
85%OPC-15%PPA	2.00	38.8	148 (225)
80%OPC-20%PPA	1.85	40.0	160 (240)
75%OPC-25%PPA	1.60	42.5	180 (270)

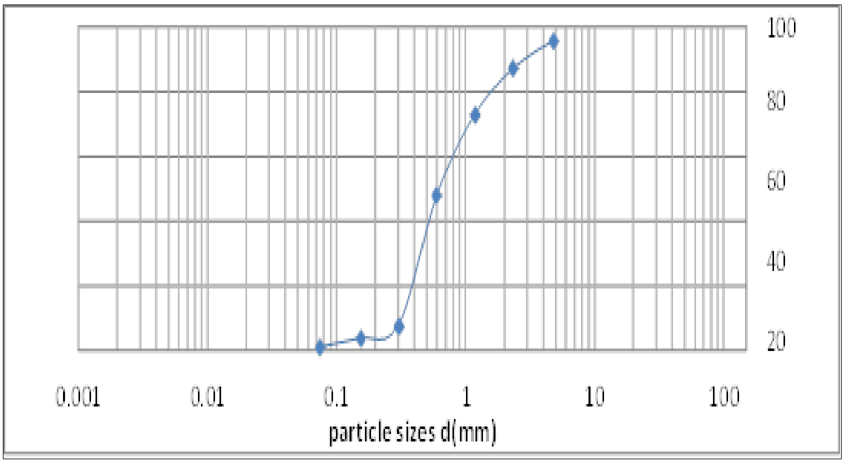

Figure 1 Result of Particle Size Distribution for Sand

It can be seen that the materials used conform to the specifications of the relevant codes governing their usage.

3.2. Oxide Composition and Compressive Strength.

The result of XRF analysis carried out on the Ordinary Portland Cement and Plantain Peel Ash at the Centre for Energy Research, Ahmadu Bello University Zaria is presented in table 2. It can be seen that the combined quantities of SiO_2+Al_2O_3+Fe_2O_3 in the PPA is less than the 50% required for pozzolanas. Also, the CaO quantity is small while the quantity of K2O in PPA is very large. Since SiO_2 is instrumental to the pozzolanic reaction, it is obvious from a theoretical perspective that addition of Plantain Peel Ash to Ordinary Portland Cement will add little to the strength of mortar and concrete vis-à-vis the pozzolanic reaction. This is due to the small amount of SiO_2 present for the pozzolanic reaction. Also, the high quantity of K_2O could trigger the production of KOH during the hydration process which could be detrimental to strength development.

Table 2 Oxide Composition of Plantain Peel Ash and Ordinary Portland Cement

Oxide	CaO	Fe_2O_3	Al_2O_3	SiO_2	TiO	K_2O	Na_2O	SO_3	BaO	P_2O_5	LOI
PPA	6.83	3.21	5.73	13.50	0.36	71.41	0.03	1.92	0.11	4.32	4.18
OPC	65.57	6.83	5.60	16.20	0.20	0.48	0.78	2.51	0.12	-	0.09

The result of compressive strength is presented in table 3. It can be seen that the compressive strength increases with curing age for all percentage replacements but decreases with percentage inclusion of PPA for any particular age. While the rate of strength gain increases with curing age for the control (0% PPA), it decreases with age for mortar containing

Plantain Peel Ash. This could be due to the small quantity of SiO_2 present for the pozzolanic reaction which gets used up and therefore the decrease in the rate of the hydration reaction as the mortar ages.

Table 3 Compressive Strength of Plantain Peel Ash and Ordinary Portland Cement Mortar

Curing age	Compressive strength at different % replacement of OPC by PPA (N/mm^2)					
	0% PPA	5% PPA	10% PPA	15% PPA	20%PPA	25%PPA
7 days	5.62	4.28	3.21	2.14	1.87	1.20
14 days	5.75	4.41	4.14	3.07	2.40	1.47
28 days	6.69	4.55	4.42	2.41	3.01	1.87

Mortar deteriorates when subjected to acidic environment. The rate of deterioration is higher for normal mortar as compared to OPC-PPA mortar; the presence of PPA reducing the rate of deterioration. This is attributed to the high quantity of K_2O which produces an alkaline environment to counteract, to a large extent, the effect of the acidic curing environment. This shows that the presence of PPA has a positive effect on the durability of the mortar in acid. The result agrees with a similar research by [14].

3.3. Durability Performance of OPC-PPA mortars.

The result of durability performance measured using sorptivity, apparent porosity and water absorption are presented in figs 2, 3 and 4 respectively.

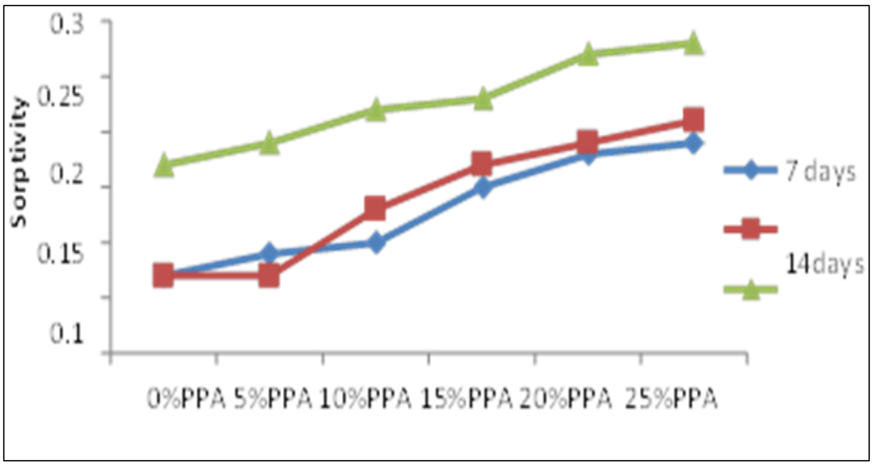

Figure 2 Sorptivity with Percentage Replacement

It can be seen from fig 3 that sorptivity increases with both curing age and percentage inclusion of PPA. Mortar specimens with higher sorptivity values lose more strength than those with lesser corresponding values [12]. This result shows that sorptivity values of up to 10%PPA falls within the acceptable range proposed by [13]. This result shows that water absorption in the mortar through the interconnected pore spaces increases as the percentage of PPA increases. This can translate to a higher deterioration rate.

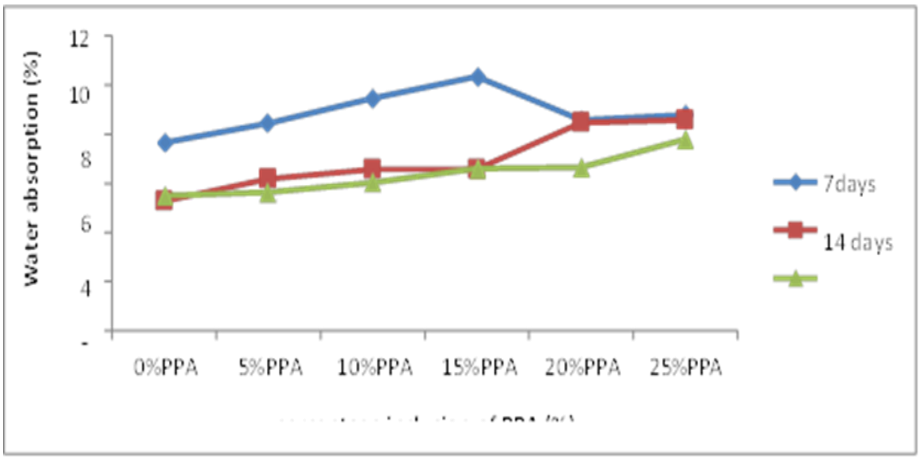

Figure 3 Water Absorption

The percentage water absorption generally decreases with age but increases with percentage inclusion of PPA to the mortar. This means that addition of PPA generally increases the water permeability of the mortar. This is in agreement with work done by [12] who observed that specimens containing lesser alkali (Na2O) were found to possess higher water absorption and lost more strength than those with lesser values after 24 weeks of exposure in sulfuric acid.

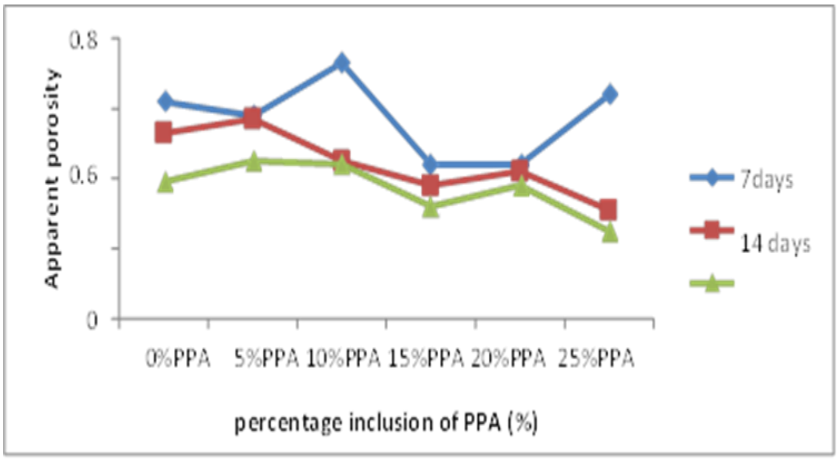

Figure 4 Apparent Porosity

The apparent porosity decreases with curing age but shows no definite pattern with percentage inclusion of PPA.

4. Conclusion

The following conclusions are reached on the basis of this research

- Plantain Peel Ash contain less than 50% SiO_2+Al_2O_3+Fe_2O_3 stipulated by ASTM C 618 which means it is not a pozzolanic material and thus not suitable for use as a SCM since inclusion of PPA to cement mortar decreases the compressive strength of mortar at all ages and percentage inclusions.
- PPA blended mortars shows better performance in acidic environment than normal mortars and can thus be used as filler in concrete and mortar in acidic environments.
- OPC mortars have better durability performance, measured using sorptivity, apparent porosity and water absorption than PPA blended mortars.

It is recommended that micro and nano-based analysis be carried out on PPA blended concretes and mortars to investigate the effect of the material on the pore characteristics as well as the effect on the hydration properties of cement.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

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