PROPERTIES OF CONCRETE MADE WITH ORDINARY PORTLAND CEMENT PARTLY REPLACED WITH RICE HUSK ASH AND PULVERISED-FUEL ASH

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ABSTRACT: *The use of pozzolana as a Supplementary Cementing Material (SCM) in concrete production has become common all over the world. When properly used, pozzolanic materials can significantly enhance the properties of concrete. Laboratory study was conducted in Nigeria to investigate the properties of concrete made by partial replacement of Ordinary Portland Cement (OPC) with Rice Husk Ash (RHA) and Pulverised Fuel Ash (PFA) that were locally available in the country. Concrete cubes and cylinders were cast at a constant water/binder ratio of 0.6 and moist cured for 7, 28 and 56 days using the above cementitious materials. Measurements of the workability, compressive strength and porosity were determined. The results show that the use of ternary blend of OPC, RHA and PFA produces concrete with improved strengths and permeability at the low replacement level with RHA and PFA and at the later age in comparison to that of OPC concrete. Although, the results of the compressive strength of the concrete cubes made from the Portland-Pozzolana Cement (PPC) were not higher than that of the control, they can be used for masonry, non-structural works and foundations were low strength are needed.The porosity of concrete containing pozzolana reduces with the low replacement level of up to 20% of pozzolana, but increases with the 30% replacement level. The workability of the concrete made with RHA decreases with an increase in ash content compared to the PFA.*

Keywords: Supplementary Cementing Material, Rice Husk Ash, Pulverised Fuel Ash, Compressive Strength, Porosity.
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INTRODUCTION

Due to the growing environmental concern and the need to conserve energy and resources researches have been directed towards the utilization of waste as building materials [1, 2 and 3]. For the construction industry, the development and use of pozzolanic materials is growing rapidly. Pozzolanas from industrial and agricultural by-products such as rice husk ash, pulverised fuel ash, condensed silica fume and ground granulated blast furnace slag are receiving more attention now since their uses generally improve the properties of both fresh and hardened concrete, reduce heat of hydration which is especially important in large concrete pours, improve resistance to a range of durability threats, such as sulfate attack and alkali aggregates reactivity and the reduction of negative environmental effects and concrete cost. Rice husk is one of the major agricultural by-products and is cultivated in many parts of the world. When rice husk is burnt at temperatures lower than 700^{0}C, rice husk ash with cellular microstructure is produced. Rice husk ash contains high silica content in the form of non-crystalline or amorphous silica. Therefore, it is a pozzolanic material and can be used as supplementary cementitious materials [4]. Pulverised fuel ash is produced as a by-product from the pulverization of coals [5]. Investigation of the additions of PFA in concrete noticed improved strength and reduced permeability, also an increased resistance to chloride penetration and alkali-silica reactivity were also identified [6]. Porosity of concrete paste increases as a result of the incorporation of PFA with the reduction of the average pore size, resulting in a less permeable paste [7, 8]. In this work, rice husk ash and pulverised fuel ash that are sourced locally were used as base materials for studying the binary and ternary blended cement. The influence of these materials on the compressive strength and permeability of concrete is discussed and the results are compared with those obtained with control Portland cement concrete. The knowledge in terms of strength and porosity would be beneficial to the understanding of the microstructures as well as for future applications of these materials in Nigeria.

EXPERIMENTAL PROGRAM

Materials

The rice husk was obtained from rice milling facilities dump sites in Idah, Nigeria. Open burning was carried out in small heaps of 100 kg rice husk with maximum burning temperature of 650^0C. Pulverised fuel ash used in the study was obtained from burning coal from the Okaba mine deposit in Kogi state, Nigeria. Dangote brand of Ordinary Portland Cement (OPC) was used in the study.

Erosion sand with specific gravity of 2.62, fineness modulus of 2.83 and water absorption of 0.82% and pebbles stone with nominal maximum size of 21 mm, specific gravity of 2.73 and water absorption of 1.10% were used as fine and coarse aggregates respectively. Both the fine and coarse aggregates were separated into different size fraction and then recombined to a specific grading.

Mix Proportions and Curing

Cementing materials used in the study comprises of binary and ternary mixes of cement and pozzolana. Sand-to-binder ratios of 2.75 by weight, water to binder ratio of 0.6 were used. Concrete samples were cast following the standard procedure; cast samples were covered with plastic sheet in a room where the temperature is controlled at 22 ± 2^0C and were demoulded at the age of 24 ± 4 hours after casting. For strength and porosity tests, the samples were moist cured at 23 ± 2^0C until the test ages. The concrete mix number and mix proportions are given in Table 1.

Table 1: Mixture Proportions (Kg/m^3) of the Various Concretes Tested

Mix No.	Water	CEM I	RHA	PFA	Stone	Sand	W/b
M1	210	350	0	0	1015	962	0.6
M2	210	315	35	0	1015	962	0.6
M3	210	315	0	35	1015	962	0.6
M4	210	280	70	0	1015	962	0.6
M5	210	280	0	70	1015	962	0.6
M6	210	245	105	0	1015	962	0.6
M7	210	245	0	105	1015	962	0.6
M8	210	280	35	35	1015	962	0.6
M9	210	245	52.5	25.5	1015	962	0.6
M10	210	210	70	70	1015	962	0.6

Compressive Strength Test

The concrete cube samples of size 100x100x100 mm were used for the compressive strength test of concrete. They were tested at the age of 7, 28 and 56 days. The test was done in accordance with ASTM C109 [9]. The strength was calculated using equation 1.

$$R_c = \frac{F_c}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (1)$$

Where;

Rc = The compressive strength in per square millimeter $[N/mm^2]$

Fc = The maximum load at fracture, in Newton's [N]

A = The area of the load bearing plates, in square millimeter $[mm^2]$

Results recorded are average of three samples as shown in Figure 1.

Porosity Tests

Cylindrical specimens of 100 mm diameter and 200 mm height were prepared in accordance with ASTM C39 [10]. They were tested at the age of 7, 28 and 56 days. After being cured in water until the age of 7, 28 and 56 days, they were cut into 50 mm thick slices with the 50 mm ends discarded. They were dried at 100 ± 5^0C until constant weight was achieved and were then placed in desiccators under vacuum for 3 hrs. The set-up was finally filled with de-aired, distilled water to measure the porosity of the concrete. The porosity results are average of two samples as shown in Figure 2. The porosity was calculated using Eq. 2.

$$P = \frac{(W_a - W_d)}{(W_a - W_w)} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (2)$$

Where:

P = Vacuum saturated porosity [%]

W_a = Specimen weight in air of saturated sample [g]

W_d = Specimen dry weight after 24 hrs in oven at 100 ± 5^0C [g]

Ww = Specimen weight in water [g]

This method has been used to measure the porosity of the cement-based materials successfully [11, 12].

RESULTS AND DISCUSSION

Characteristics of OPC, RHA and PFA

The fineness characteristics of ordinary Portland cement and pozzolanic materials are given in Table 2. The Blaine fineness of OPC is 3500 cm^2/g and those of the RHA and PFA are 12,200 and 5400 cm^2/g. The specific gravity of the OPC, RHA and PFA are 3.14, 2.24 and 2.47 respectively. The mean particle sizes of OPC, RHA and PFA are 14.0, 9.8 and 5.4 µm, respectively.

Table 2: Physical Properties of OPC, RHA and PFA

Sample	Median Size (µm)	Particle Retained on a Size No. 325 (%)	Specific Gravity	Blaine Fineness (cm^2/g)
OPC	14	-	3.15	3500
RHA	9.8	1-3	2.24	12200
PFA	5.4	1-3	2.47	5400

The chemical constituents are given in Table 3. Pulverised fuel ash is a Class F fly ash with 75.1 % of SiO_2 + Al_2O_3 + Fe_2O_3, 2.4 % of SO_3 and 2.7 % of LOI meeting the requirement of ASTM C618 [8]. The CaO content of the pulverised fly ash is high at 13.9 % as it is from lignite. RHA, on the other hand consists mainly of SiO_2 and the other components are not significant. The SiO_2 content of 93.2 % satisfies ASTM C618 [8] requirement as a natural pozzolana and 3.9 % LOI indicates complete burning.

Table 3: Chemical Composition of OPC, RHA, and PFA

Oxides	OPC	RHA	PFA
SiO_2	20.9	93.2	42.4
Al_2O_3	4.8	0.4	21.6
Fe_2O_3	3.4	0.1	11.1
CaO	65.4	1.1	13.9
MgO	1.3	0.1	3.3
Na_2O	0.2	0.1	1.1
K_2O	0.4	1.3	2.6
SO_3	2.7	0.9	2.4
LOI	0.9	3.9	2.7
$SiO_2 + Al_2O_3 + Fe_2O_3$	–	93.9	75.1

Compressive Strength Results

Compressive strength results of the studied concrete are shown in Figure 1. The strengths of the concrete containing RHA, PFA at both the binary and ternary blended mixes were all lower than the control OPC at all ages, though at later ages the percentage difference reduces for all the concrete tested. The strengths of concrete containing Pozzolana increases with curing time as noticed also with the control Portland cement concrete and decrease as the percentage replacement of the ashes increases. Only the strength at 56 days of concrete containing these pozzolanic materials is slightly closer to the OPC concrete. This indicates that both PFA and RHA are pozzolanic materials and the early pozzolanic reaction rate is thus slow. The incorporation of these materials produces filler and dispersing effects and increases the nucleation and precipitation site [7]. The incorporation of RHA also produces the filler effect due to its fine particle size.

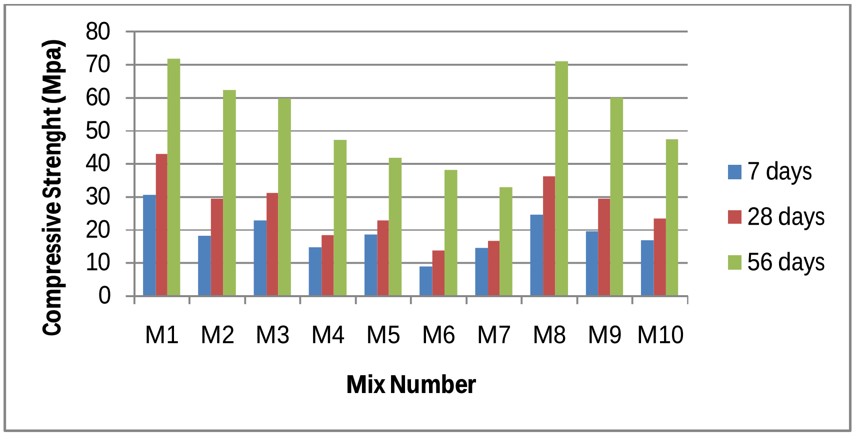

Figure 1: Compressive Strength Results for the Mixes at Different Curing Age

The increase in the amount of replacement to 30 % reduces the early strength of both RHA and PFA concrete. However, the strength at the ages of 28 and 56 days of both PFA and RHA concrete are slightly closer to the control for the 10 % replacement. This indicates that both PFA and RHA are pozzolanic materials and the early pozzolanic reaction rate is thus slow. The pozzolanic reaction of both cases, however, can be seen at the age of 28 days onwards resulting in the higher strength of both PFA and RHA concrete in comparison to that of the control. The results also suggest that both PFA and RHA in this experiment were quite reactive and the pozzolanic reaction starts quite early.

For the blend of pozzolanas, the strengths of concrete are also comparable to that of OPC concrete at the same age. The strengths at the age of 7 days blended Pozzolana concrete range between 97–99% of that of OPC. At the age of 28 and 56 days, the normalized strength ranges between 92–95% and 90–94%, respectively. The results indicate that for the high replacement level of 20%, the use of blend of RHA and PFA improves the early strength development of concrete in comparison to normal single pozzolana concrete. The incorporation of blend of fine pozzolanas improves the strength of concrete due to synergic effect [13].

Porosity Results

The results of the porosity of studied concrete at 7, 28 and 56 days are shown in Figure 2. At the age of 7 days, the porosities of concrete containing 10%, 20% and 30% of pozzolanas and blend of pozzolanas are slightly lower than that of the control at all ages. The addition of fine particles of PFA and RHA causes segmentation of large pores and increases nucleation sites for precipitation of hydration products in cement paste [14]. This results in pore refinement and a reduction of calcium hydroxide ($Ca(OH)_2$) in the paste as a result of dilution effect and pozzolanic reactions. The concrete containing PFA gives slightly less porosity than that of RHA. In other word, PFA is slightly more effective in modifying pore and reducing the porosity of concrete. The porosity of M4 concrete is 17.1% in comparison with 17.9% of both M1 and M5 concrete.

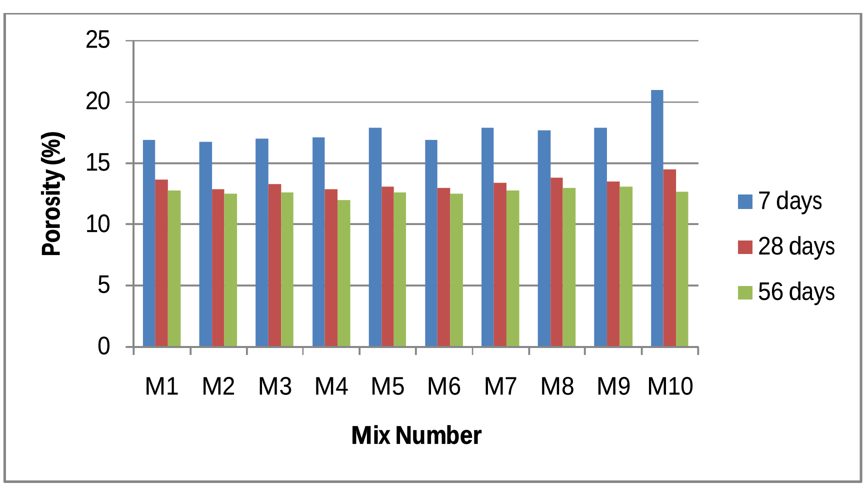

Figure 2: Porosity Results for the Mixes at Different Curing Age

At high replacement level of 30%, the porosities of the concrete containing pozzolanas increase in comparison with that of the control. At the age of 7 days, the porosities of M8, M9 and M10 mixes are 16.9%, 17.7% and 21.3% which are significantly larger than 16.9% of the OPC concrete. The increases in porosity with a relative large amount of pozzolanas resulted from the reduced amount of OPC. This results in less hydration products especially at the early age where the pozzolanic reaction is small. It should be pointed out here that although the porosity is increased, the beneficial effect of pore refinement as a result of the incorporation of pozzolana exists. The porosities of the concrete reduce with an increase in age as expected. This is due to the increase in the hydration of cementitious materials. At the later age of 56 days, the porosities of the concrete containing pozzolanas reduce to similar values to that of OPC concrete. The porosities of M8, M9 and M10 mixes at 56 days are 12.5%, 12.7% and 13.9% as compared to 12.8% of OPC concrete at the same age.

CONCLUSIONS

Based on the limited experiments, the following conclusion may be drawn.

1. The use of ternary blend of OPC, RHA and PFA significantly improves the concrete in terms of strength and porosity at later age. And specifically strength at lower replacement level and porosity at higher replacement level comparable to the control Portland cement.
2. The incorporation of the RHA in concrete reduced the porosity compared to the PFA and the OPC with the PFA having lower porosity that the control OPC. This is perhaps as a results of reduced $Ca(OH)_2$ in the interfacial zone compared to the control Portland cement [15].
3. The concrete incorporating PFA did not show any increase in the compressive strength compared to the RHA and the control Portland cement concrete. The higher strength of the RHA at all the replacement level compared to the PFA is due probably to its reduced porosity, reduced $Ca(OH)_2$ content and the reduced width of the interfacial zone between the paste and the aggregates [15].

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