Energy Efficient Cementitious Material: An Option for Low Cost Housing Schemes

Emmanuel Emem-Obong Agbenyeku, Edison Muzenda and Innocent Mandla Msibi

Abstract**—**Energy efficient and cost saving cement alternatives have been identified for use by researchers without compromising standards. The utilization of artificial pozzolanas as Cementitious Materials (CMs) in cement chemistry and engineering is widely known. Nevertheless, there is continual search for optional and greener substitutes. The use of Rice Husk Ash (RHA) as CM was studied. The abundance of RHA and the need for low cost shelter triggered this investigation looking into chemical composition of the generated ash and the compressive strength of the concrete type produced by partly replacing Ordinary Portland Cement (OPC) with RHA under short hydration periods. 60 cubes of 300 mm dimensions were cast with cement substituted by RHA ranging from 0-40%, adopting 28 day targeted strength of 25 MPa as control. Specimens hydrated at relative humidity (RH) of 95-100% and temperature (T) of 22-25^{0}C in a chamber for 7, 14, 21, and 28 days. Results revealed trends of strength gain and reduced density with increase in RHA. The 28 day density and strength of the control specimen was 2465 kg/m^3 and 28.6 MPa while the 10% RHA sample (i.e. best replaced matrix) had 2398 kg/m^3 and 26.0 MPa respectively. The strength of 10% RHA/OPC product (26.0 MPa) was slightly higher than the adopted strength (25 N/mm^2) at 28 days. This can serve as cost saving means in rural housing schemes with less structural demands.

Keywords**—***Rice Husk Ash (RHA), Pozzolanas, Compressive strength, Agricultural Waste*

I. Introduction

THE production of cementitious materials (CMs) is imperative to developing countries as low-cost construction materials as self-sustaining means of shelter. Increasing prices of conventional materials has caused the search for locally available alternatives. These alternatives are to partly or wholly replace the costly conventional materials in mortar and concrete. From cement chemistry, CMs have been found to improve concrete properties. Their production is also energy efficient as compared to OPC. As such, the environment is protected and conserved by saving energy, natural resources and reducing carbon footprint [1]. Studies have therefore, shown waste ash to be suitable as options in concrete manufacture [2-3]. Their pozzolanic properties give technical merits and increased cement replacements [4]. Most portions of the binder used in construction is the OPC produced by mixing naturally occurring substances of calcium carbonate with substances of alumina, silica and iron oxide [5]. OPC mixed with fly ash (FA) and silica fume (SF) are generally accepted while OPC mixed with artificial pozzolans like sugar cane ash (bagasse) and burnt oil shale are only used where they are familiar. In pozzolans, amorphous silica present reacts with lime to form cementitious materials. These materials advance durability of concrete, improve strength gain and reduces rate of heat of hydration. Studies toward fully or partly replacing locally available pozzolanas from farm wastes like millet husk ash, corn cob ash and sorghum ash in concrete are been done [6-7]. This paper however, studied the effect of partly mixing locally available RHA with OPC on the strength of the concrete product under short term hydration. The incorporation of RHA- an unsightly nuisance farm waste into concrete is an option to using farm waste as part of a cheap and functional greener product. 28 days strength was as trial test for pozzolanic activity [8].

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II. Review of Related Literature

Substituting OPC with locally available pozzolanas is well recorded [9-10]. “Pozzolana” is a naturally occurring and artificially siliceous or siliceous and aluminous material which in itself has little or no cementitious properties. Nonetheless, in finely divided state and when water is added, react with calcium hydroxide during the hydration of OPC at normal temperatures to form compounds with adequate binding properties [10-11]. Trends on alternative locally available materials have been on partly or fully replacing OPC in concrete, revealing that pozzolanas can form concrete with similar properties as normal concrete at age 28 days and beyond. Rice as a cereal grain is the main staple food for a larger part of the world's population. It is a grain with the second-highest worldwide consumption after maize (corn). Rice husk is the outer covering of rice grain [12], consisting of two interlocks and is an enormous farm waste typically generated in tonnes during manual or mechanical threshing as seen in Fig. 1. Rice husk is a finely divided particle of farm waste measuring <1/9 mm in diameter [10-13]. It is obtained after rice grain is removed from its shell. Rice is normally grown as annual plants around the world although in tropical and sub-tropical areas it survives as perennials and can produce a ratoon crop for up to 30 years. This indicates its availability as raw material by its high consumption rate. RHA is however, obtained after combusting the husk in open air or furnace (see Fig. 2) at temperatures between 650-700^{o}C to produce highly reactive amorphous ash [12]. RHA is a fine pozzolanic material which by itself is poorly cementitious but in the presence of lime and water forms a cementitious compound [14].

Fig. 1 Rice husk disposed as farm waste in heaps

Fig. 2 Rice husk clinks formed from incineration

Pozzolanic value of RHA relies on controlled burning conditions and its colour depends on carbon content of the ash. Highly amorphous pozzolanic ash is produced from controlled incineration temperature range $\geq 700^0$C. Applications of various ashes as alternatives in mortar and concrete have gained attention over time. These alternatives do not only contribute to improvement of concrete performance (i.e. increased strength, durability and reduction of heat of hydration) but also reduces energy consumption and carbon emission by OPC producing plants. Therefore, experimental works on various waste compositions (i.e. waste ashes and potential pozzolanic materials) such as; tailings, blast furnace slag, pulverized fuel ash, sawdust ash, wheat ash, sugar cane fibre ash (bagasse) and groundnut husk ash are been investigated [6].

III. EXPERIMENTAL APPROACH

Rice husk used herein was collected as waste from an open dump around a local milling farm in Lafia, Nassarawa State of Nigeria where presently, about 700 fully functional mills produce rice for consumption. The rice husk were sun dried, burnt in open air to reduce the particle sizes and calcined in a controlled electric furnace to a temperature of 700ºC for 2hours to ensure highly reactive ash as shown in Fig. 3.

Fig. 3 Amorphous RHA from incineration and finely ground

The reactive amorphous ash nodules were crushed and sieved through 75 µm mesh. RHA chemical content determined by X-Ray diffraction and X-Ray fluorescent are presented in Table 1. Analysis shows the cumulative content of Silicon Dioxide (SiO_2), Aluminium Oxide (Al_2O_3) and Iron Oxide (Fe_2O_3) to be 75.87% which is above the minimum of 70% as specified in [8]. Hence, indicates RHA to possess significant pozzolanic tendencies. RHA/OPC ratios ranging from 0-40% replacement (produced in triplicates) were crushed. The control specimen (i.e. normal concrete) was proportioned for a targeted strength of 25 MPa in accordance with British Mix Design (D.O.E) method as the required minimum strength for structural concrete in agreement with BS8110.

TABLE I
CHEMICAL COMPOSITION OF RHA (%)

Chemical composition	SiO_2	AL_2O_3	Fe_2O_3	SiO_2+ AL_2O_3+ Fe_2O_3
FA	66.2	6.95	2.72	75.87

The mix proportion used herein was 1:2:4. "Lafarge", locally produced ASTM Type I PC specifications [15] was used. The proportions of OPC/RHA in the concrete were 100:0% (as control), 90:10%, 80:20%, 70:30% and 60:40% respectively. The OPC/RHA replacement was computed by mass. Properties from preliminary test results of material composition are shown in Table 2. The fine aggregate used was sharp sand free from dirt and particles while the coarse aggregate was 19 mm (3/4") specific maximum size obtained from "Group5" Constructions, South Africa. All aggregates were according to specifications in [16] and tap water was used for concrete mixing while hydration was done in a chamber. Effect of various percentage replacements of RHA on the compressive strength and densities of the product were investigated over short term hydration. For the compressive strength to be determined 60 specimens of 300 mm cubic dimensions were moulded and hydrated at RH of 95-100% and T of 22-25^{0}C in a chamber for 7, 14, 21, and 28 days. Table 3 shows the data from the short chamber hydration series for all the tested specimens.

TABLE II
PHYSICAL PROPERTIES OF MATERIAL COMPOSITION

Parameters	RHA	Sand	Granite
Specific Gravity	2.97	2.55	2.63
Bulk Density (kg/m^3)			
Uncompacted	1397	1375	1354
Compacted	1486	1428	1343
Void (%)	15.55	10.24	24.36
Moisture Content (%)		3.59	
Sieve Analysis			
Fineness Modulus (m^2/kg)		2.53	
Coefficient of Uniformity (Cu)		8.05	1.43
Coefficient of Gradation (Cg)		1.04	0.95

Permeable sacks were used to cover the samples and water was constantly sprinkled on the cover through the entire hydration [17]. At the end of every hydration period, 3 specimens as shown in Fig. 4, of each mix were tested under direct loading from a compression test device and average values recorded.

TABLE III
DENSITY (DEN-kg/m^3) AND COMPRESSIVE STRENGTH (CS-MPa) OF CONCRETE SPECIMENS

		Short term chamber hydration period							
OPC (%)	RHA (%)	7		14		21		28	
		Den	CS	Den	CS	Den	CS	Den	CS
100	0	2435	18.1	2448	21.9	2479	25.0	2465	28.6
90	10	2429	15.9	2427	19.5	2399	23.8	2398	26.0
80	20	2397	13.5	2391	17.3	2384	20.5	2372	25.0
70	30	2279	10.0	2257	14.5	2236	18.1	2349	22.4
60	40	2248	7.9	2235	12.7	2232	16.1	2323	19.5

Fig. 4 Green concrete specimen

IV. RESULTS AND DISCUSSION

The result presented in Fig. 5 show that the percentage increase in RHA led to a decrease in the respective densities of RHA/OPC concrete.

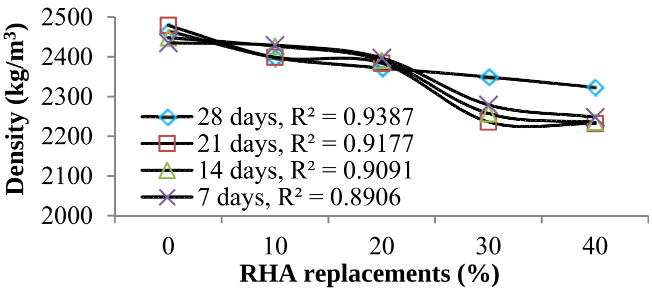

Fig. 5 Effect of RHA replacement (%) on concrete density (kg/m^3)

At 28 day hydration 0%RHA replacement (i.e. control sample) had density of 2465 kg/m^3 whereas 10%RHA substitute (i.e. best replaced matrix) had density of 2398 kg/m^3 showing a loss of about 2.7% which can be as a result of the difference in the fineness modulus of RHA with respect to cement. Their compressive strengths were gotten as 28.6 MPa and 26.0 MPa respectively. Fig. 6 shows the compressive strength comparison between the control sample and the replacement matrices. Strong correlation between the compressive strength and the hydration periods was observed. Although, the strength of cement blended with pozzolana improves with age since pozzolanas react more slowly than cement due to difference in composition but obtain similar strength after about a year. The results show a trend of gradual strength development of the green concrete as the hydration increased.

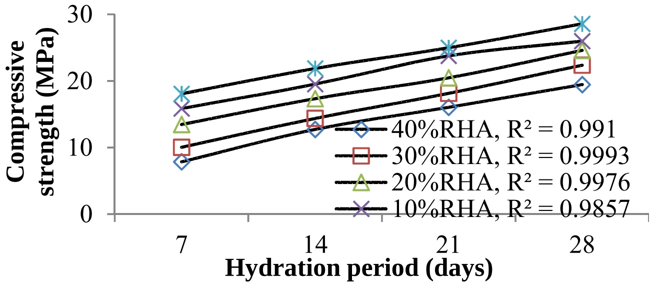

Fig. 6 Compressive strength (MPa) of respective concrete samples

Hence, there is high tendency for this concrete type to attain strength values similar to the control sample at prolonged hydration periods. Fig. 7 reveals a drop in concrete density with increased hydration. This can be accounted for by water absorption and the simultaneous loss in materials.

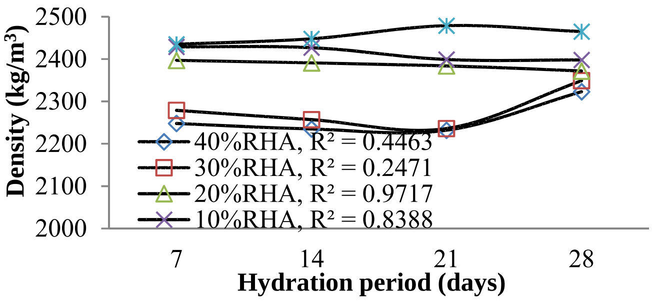

Fig. 7 Effect of hydration (days) on concrete density (kg/m^3)

However, the trend is not linear as the densities of specimens with higher contents of RHA are seen to increase at 21-28 days hydration. The increased densities experienced by the specimens with higher percentage of RHA are associated with the addition of RHA and the changes in the water absorption potentials of the mixes. As such, fairly strong correlation between the concrete density and hydration period is observed. Strong correlation is also seen between the compressive strength of the samples and the percentage RHA replacements. The progressive drop in the strength of samples with increase in RHA over the different hydration periods as shown in Fig. 8 is associated with the excess idle amorphous silica and/or alumina from RHA not used up in the reaction.

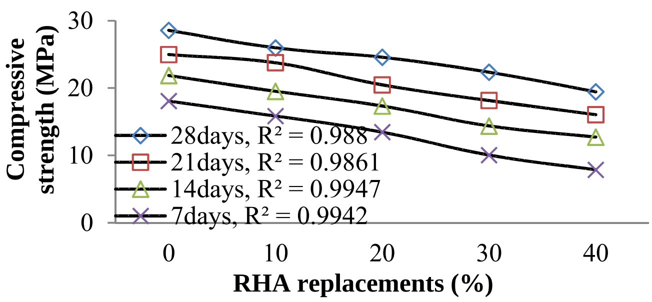

Fig. 8 Effect of RHA replacement (%) on concrete compressive strength (MPa)

Hence, the excess RHA simply contributed to the loss in strength. For 28 day strength, it is therefore required that the limit to which cement be replaced for quality and economy should be 20% as per [8].

V. CONCLUSIONS

The exploitation of artificial pozzolanas as CMs was looked into in this study in search for optional and greener substitutes. RHA as CM was studied based on its availability and for the dire need of low cost housing in developing countries. The outcome of partly replacing OPC with RHA under short hydration periods gave rise to the following conclusions:

- The results presented revealed that the 10%RHA replacement (i.e. the best matrix) had 28day strength of (26.0 MPa) which is less than the control specimen (28.6 MPa) but is above the targeted strength (25 MPa). Hence satisfies the minimum strength for structural concrete as specified by BS8110.
- The strength of green concrete samples increased with increased hydration period.
- Water absorption and simultaneous loss in materials resulted in the reduction of density of samples although, subsequent increase in density was observed for specimens with high RHA content at later periods.
- The introduction of RHA presents a good tendency of pozzolanic activity.
- Over the hydration periods significant loss in strength of samples was recorded due to idle RHA quantities that were not utilized in pozzolanic reaction.
- This paper therefore illustrates how the use of RHA is an option in converting abundantly available cheap farm waste into useful resource for developing countries. Hence, the green concrete product can at the moment be used to construct simple foundations and masonry walls meanwhile, further investigations are recommended on extended hydration periods of up to 120 days to assess the pozzolanic behaviours, strength, durability, resistance to fire and corrosion of this new concrete product.

ACKNOWLEDGMENT

The Authors appreciate the University of Johannesburg where the study was carried out.

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