Blended Rice Husk Ash (RHA) Concrete; A Marginal Green Construction Material from Extended Hydration

Agbenyeku Emem-Obong Emmanuel, Aneke Ikechukwu Frank

Abstract— Numerous research findings have shown the cost saving benefits and potencies of using pozzolanas in blending cement without compromising standards. The use of artificial pozzolanas as Supplementary Cementitious Materials (SCMs) in concrete engineering is well established. In the continual search for substitute building/construction materials, the introduction of Rice Husk Ash (RHA) as a cementitious material in green concrete was investigated. The availability of this material provided the impetus for the study of the compressive strength of concrete using RHA as a partial replacement for Ordinary Portland Cement (OPC). Chemical analysis on RHA showed it to have significant qualities of a pozzolana. A total of 60 cubes of 150mm dimensions were cast with the percentage cement replacement by RHA ranging from 0 to 40% while 28-day targeted strength of 25MPa was adopted as control. The cubes were cured at a relative humidity of 95 to100% and temperature of 22-25 ^{0}C in a curing chamber for extended periods of 56, 90, 120 and 150-days. The results and analysis showed trends of strength development, revealing a decrease in the density and compressive strength of samples with increase in RHA content. The 150-days density and compressive strength of the normal concrete was 2459Kg/m^3 and 77.03MPa while the 10%RHA sample (i.e. best replacement matrix) had 2395Kg/m^3 and 78.79MPa respectively. The strength of 10%RHA/OPC concrete (78.79MPa) was higher than the strength of the control specimen (77.03MPa) at 150-days; which proves that pozzolanas can produce concrete with close characteristics as normal concrete beyond age 28-days, thereby making it a suitable green construction material. It can be a major cost reduction factor in rural housing and development; where buildings of less structural emphasis are needed. As such, it can be employed in the construction of simple foundations and concrete composites.

Index Terms— Rice Husk Ash, Pozzolanic properties, Cement, Compressive Strength, Agricultural Waste.

1 INTRODUCTION

The development of supplementary cementitious materials (SCMs) has become essential in the advancement of low-cost construction materials for production of self-sufficient housing especially in developing countries. In recent past, the insistent rise prices of conventional construction/building materials have caused enormous efforts from government, public and private sectors to sort for locally available materials as alternatives. These alternative materials are to supplement (i.e. partly or totally substitute) the scarce and expensive conventional materials particularly in mortar and concrete production. The use of these SCMs as admixtures not only improves concrete properties but protects and conserves the environment by saving energy and natural resources [1]. Thus, studies have been conducted to find the suitability of waste ash to replace cement in conventional concrete [2], [3], [4], [5]. Inert fillers in small amounts are acceptable as cement replacement. Their pozzolanic properties convey not only technical advantages to the resulting concrete but also enable larger quantities of cement to be successfully substituted [6].

- *Agbenyeku E.E. is a graduate research student in civil engineering science, University Johannesburg, South Africa, APK Campus, P.O.Box 524, 2006. E-mail:kobitha2003@yahoo.com*
- *Aneke I.F. is a graduate research student in civil engineering science, University Johannesburg, South Africa, APK Campus, P.O.Box 524, 2006. E-mail:Frankaneke4@gmail.com*

According to ECO-CARE [7], bulk of the cement used in construction work is Portland cement (PC) manufactured by mixing naturally occurring substances containing calcium carbonate with substances containing alumina, silica and iron oxide. Over recent times, PCs containing Fly ash (FA) and Silica fume have gained increasing acceptance while PC containing artificial pozzolans like sugar cane ash (bagasse) and burnt oil shale are commonly used in regions where they are abundant.

In pozzolanic materials, the amorphous silica present combines with lime and forms cementitious materials. These materials can improve the durability of concrete, its rate of strength gain and reduces the rate of liberation of heat of hydration which is highly beneficial for mass concrete. Efforts are propelled toward substituting cement (wholly or partially) with locally available pozzolanic materials like cassava peels ash, volcanic ash, saw dust ash, millet husk ash, pulverized fuel ash, corn cob ash etc., in concrete [8], [9]. This paper therefore investigates the effect of merging locally available pozzolanic material Rice Husk Ash (RHA) as partial replacement for cement on the strength characteristics of concrete under extended hydration periods. The addition of RHA (a seemingly unsightly idle agricultural waste); into concrete is an approach to transforming an agricultural waste material to an affordable and functional produce. The 28-day strength is used as a trial assessment of pozzolanic activity in consonance with ASTM C618 [10].

ISSN 2229-5518

2 Review of Literature

According to Job [11], efforts have been made by researchers like Neville [12], Popovics [13] to practically substitute cement with locally available materials called pozzolanas. "Pozzolana" is used to define naturally occurring and artificially siliceous or siliceous and aluminous materials which in themselves have little or no cementitious properties but in finely divided form and in the presence of moisture, chemically react with calcium hydroxide which is liberated during the hydration of PC at ordinary temperatures to form compounds possessing cementitious properties [10], [12], [14]. Research trends on sourcing, discoveries, development and the use of alternative locally available materials have concentrated either on purely partial or total replacements of cement in concrete revealing that pozzolanas can produce concrete with close characteristics as normal concrete at age 28-days and beyond.

Rice which is a cereal grain is the most important staple food for a larger part of the world's human population. It is the grain with the second-highest worldwide production, after maize (corn). According to Ikpong [15], rice husk is the outer covering of the rice grain consisting of two interlocking and it is an agricultural waste usually generated in large quantities during manual or mechanical threshing processes as per figure 1. Neville [12], Verghese [16], defined rice husk as a finely divided particle of agricultural waste measuring less than 11/2(i.e. about 1/9mm) in diameter, it is obtained when rice grain is removed from its shell. Rice is normally grown as an annual plant around the world, although in tropical and sub-tropical areas it can survive as a perennial and can produce a ratoon crop for up to 30 years. This is a clear indication of its availability as an industrial raw material. RHA as shown in figure 3, is obtained after burning the husk in an electric furnace, allowing accurate monitoring of the burning temperature maintained within the range of 650-700^{o}C in order to produce highly reactive amorphous ash [14]. Okpalla [17], described RHA as a fine pozzolanic material, which by itself is poorly cementitious but in the presence of lime and water forms a cementitious compound. The pozzolanic value of RHA depends on the burning conditions and its colour is dependent on the carbon content of the ash. Controlled incineration of the husk to about 700^{0}C yields highly amorphous pozzolanic RHA. As observed by Nagataki [18], the application of various ashes as potential cement substitutes and replacements in mortar and concrete production has attracted the attention of researchers as materials that not only contribute to improvement of concrete performance (i.e. increased strength, durability and reduction of heat of hydration) but are also central to the reduction of energy and carbon emission from the production of cement.

Hence, researchers are involved in experimental studies on various by-product mineral admixtures (i.e. waste ashes and materials with pozzolanic potentials) such as; mining tailings, blast furnace slag, pulverized fuel ash, volcanic ash, sawdust ash, wheat ash, sugar cane fiber (bagasse) ash, and groundnut husk ash [7], [13].

3 Materials and Method

Rice Husk used in this study was gotten as open dump waste from a local milling farm in Lafia, Nassarawa State of Nigeria where at present, about 700 fully functional mills produce rice for consumption. The rice shells (husk) were sun dried, burnt in open air and calcined in an electric furnace to a temperature of about 700^{o}C. The reactive amorphous rice husk nodules (see figure 2) were finely crushed and passed through the 75µm sieve. Results of the RHA chemical content determined by X-Ray diffraction (XRD) and X-Ray fluorescent (XRF) method shown in Table 1, reveals the total 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% specified in ASTM C618 [9]. As such, indicates RHA (see figure 3) to have significant pozzolanic properties. RHA/OPC mix ratios ranging from 0 to 40% replacement (produced in triplicates) were tested. The control specimen (i.e. plain concrete) was proportioned for a targeted strength of 25MPa in consonance with the British Mix Design (D.O.E) method as the required minimum strength for structural concrete in accordance to BS8110.

TABLE 1
CHEMICAL COMPOSITION OF RHA (%)

	SiO_2	AL_2O_3	Fe_2O_3	MgO
RHA	61.8	4.49	4.95	6.14
	TiO	CaO	LOI	$SiO_2+AL_2O_3+Fe_2O_3$
RHA	-	5.42	1.45	71.24

The mix proportion used for this study was 1:2:4. "Dangote", locally produced ASTM Type I Portland cement, conforming to the BS EN 197 was used in this investigation. 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 substitution was computed by weight. Physical properties from preliminary test results of the constituent materials are shown in Table 2. The fine aggregate used was sharp river sand, free from impurities and injurious particles while the coarse aggregate was 19mm (3/4in.) specific maximum size coarse aggregate which were obtained from "Dantata and Sowoe" Construction Company Nigeria Ltd, Abuja. All the aggregates conformed to the British Standard Specification. Tap water was used for the concrete mixing while the curing process was carried out in a curing chamber.

Effect of the various percentage replacements of RHA on the compressive strength properties and demoulding densities of the green concrete type were investigated. For the comprehensive strength to be determined, a total of 60

(150mm) dimension cubic samples were cast and cured at a relative humidity of 95 to 100% and temperature of 22-25^{0}C in a curing chamber for extended hydration periods of 56, 90, 120 and 150 days.

TABLE 2
PHYSICAL PROPERTIES OF MATERIAL CONSTITUENTS

	RHA	Sand	Granite
Specific Gravity	2.97	2.55	2.63
Bulk Density (Kg/m³)			
Uncompacted	1397	1375	1354
Compacted	1486	1428	1343
Void (%)	15.55	10.24	24.36
Moisture Content (%)		3.59	
Mechanical Analysis			
Fineness Modulus (m²/Kg)		2.53	
Coeff. Of Uniformity (Cu)		8.05	1.43
Coeff. Of Gradation (Cg)		1.04	0.95

Permeable hessian bags were used to cover the samples and water was constantly sprinkled on the cover over the 56-days period up until the 150-days in accordance with the TMH1 specifications [19]. At the end of every curing age, three specimens (see figure 4) of each mixture were crushed under direct loading using the compression test machine and their averages were taken.

TABLE 3
DENSITY (Den-Kg/m^3) COMPRESSIVE STRENGTH (CS-MPa) of RHA/OPC CONCRETE

		Hydration periods							
OPC	**RHA**	**56**		**90**		**120**		**150**	
(%)	**(%)**	**Den**	**CS**	**Den**	**CS**	**Den**	**CS**	**Den**	**CS**
100	0	2462	39.37	2460	56.48	2460	76.40	2459	77.03
90	10	2396	37.96	2395	57.21	2395	78.32	2395	78.79
80	20	2370	35.83	2367	54.42	2367	76.03	2366	76.94
70	30	2345	31.98	2343	52.06	2342	73.33	2342	73.59
60	40	2319	25.64	2319	47.23	2317	54.52	2317	56.11

Fig. 1. Rice Husk (disposed as waste in open dumps)

Fig. 2. Rice Husk clinks (formed by incineration in a furnace)

Fig. 3. Smoothly ground Incinerated RHA

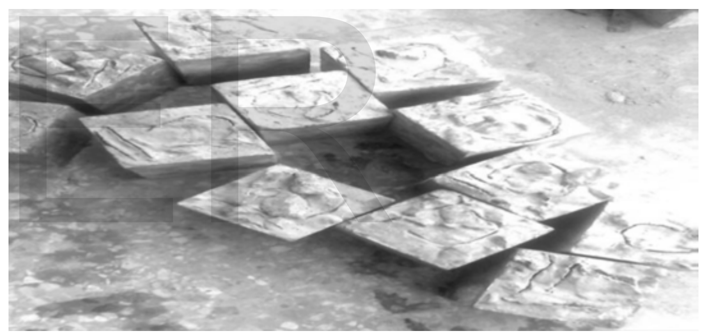

Fig. 4. RHA/OPC concrete specimens

4 Discussion of Results

Table 3 above shows the density and compressive strength values of the tested concrete samples. The result presented in Figure 5 shows that; the percentage increase in RHA, led to a decrease in the respective densities of RHA/OPC concrete.

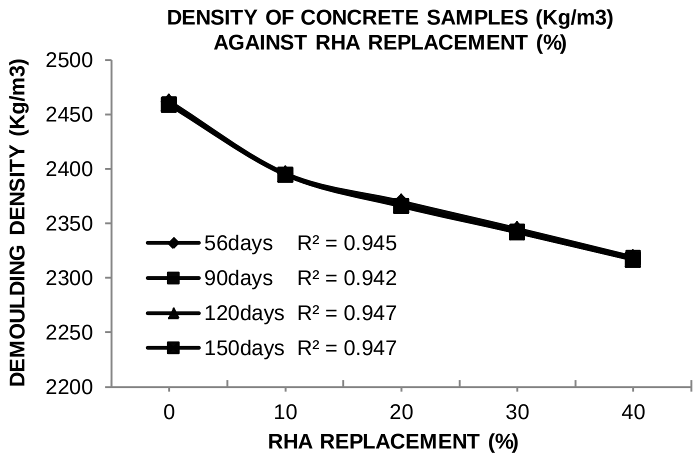

Fig. 5. Effect of RHA replacements (%) on Concrete Density (Kg/m^3)

At the 150-days hydration period, 0%RHA replacements (i.e. the control specimen), had a density of 2459Kg/m^3, at 10%RHA replacements (i.e. the best replacement matrix), the density was 2395Kg/m^3; indicating a loss of approximately 2.7% which is accounted for as a result of the difference in the fineness modulus of RHA with regard to cement, while their compressive strength were gotten as 77.03MPa and 78.79MPa respectively. The compressive strength comparison between the control sample and the replacement matrices are shown in Figure 6.

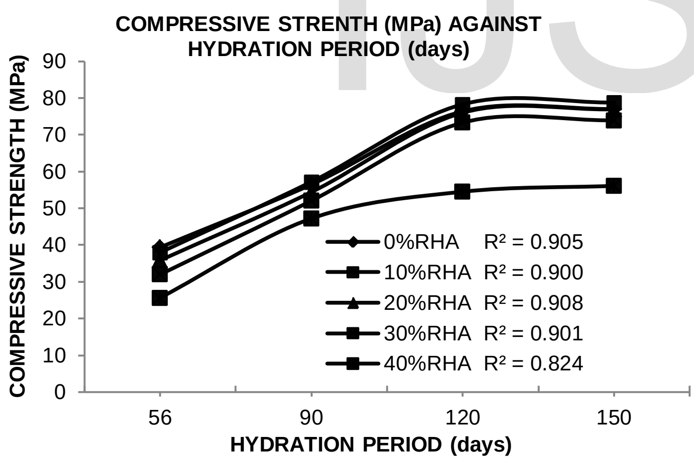

Fig. 6. Compressive Strength (MPa) of respective Concrete samples

There is a strong correlation between the compressive strength and the hydration period. Although, the strength of cement blended with pozzolanas normally improves with age since pozzolanas react more slowly than cement due to difference in composition but obtain similar strength after about a year. However, the trend shows a continual strength development of the RHA/OPC concrete to be well over the adopted 28-day strength of 25MPa for an extended hydration period. Hence, the high tendency for this green concrete type to attain strength values similar to the control sample at extended hydration periods is established.

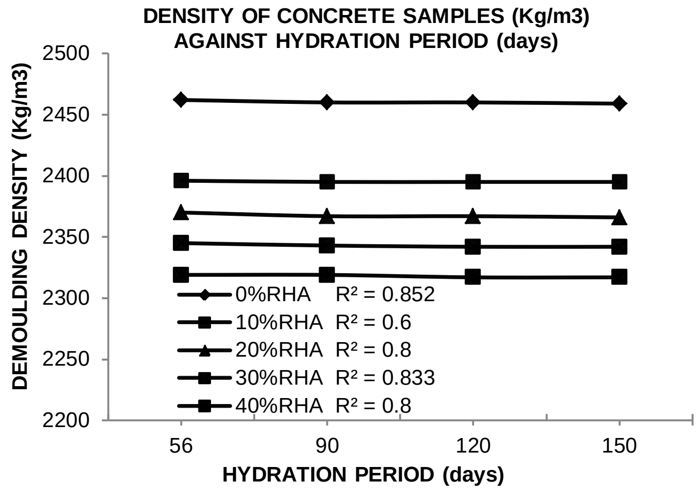

Fig. 7. Density of Concrete samples (Kg/m^3) with Hydration periods (days)

Figure 7 reveals a slight drop in concrete density with extended hydration period. This can be due to water absorption and the simultaneous loss in materials caused by the effect of prolonged wetting. However, the trend can be said to be linear as the general changes in densities of specimens for all contents of RHA are seen to share a similar pattern. The concrete samples can be said to have been saturated/equilibrated; which led to a reduced absorption of water and a subsequent reduction in the loss of material content. As such, there is a fairly strong correlation existing between the concrete density and the extended hydration period. Nonetheless, a strong correlation is seen between the compressive strength of the samples and the percentage RHA replacements.

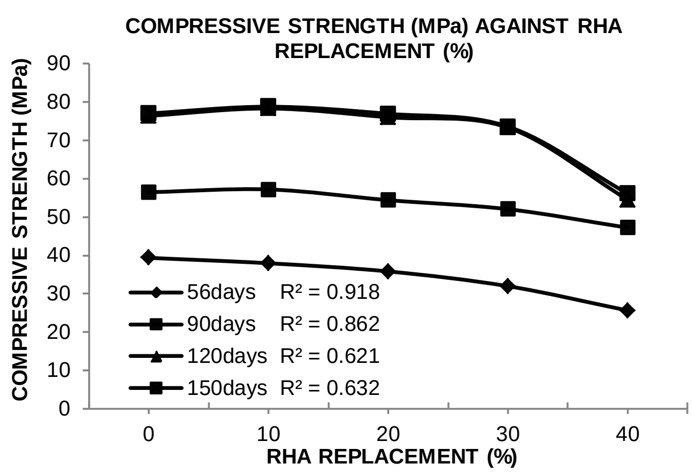

Fig. 8. Effect of RHA replacements (%) on the Strength (MPa) of Concrete

The progressive drop in the strength of samples with increase in RHA over the different hydration periods as shown in Figure 8 can be accounted for as a result of the excess amorphous silica and/or alumina from RHA not used up in the reaction. Hence, the excess RHA simply contributed to the drop in strength. ASTM C618 for 28-day strength therefore requires that the limit to which cement can be replaced for quality and economy should be 20%.

5 Conclusion and Recommendation

- The results presented revealed that the 10%RHA replacement (i.e. the best replacement matrix) had 150-days strength of (78.79MPa) which is higher than the control specimen (77.03MPa). Hence, satisfies the strength requirement for structural concrete in accordance to BS8110.
- The strength of cement blended with pozzolanas normally improves with age since pozzolanas react more slowly but can produce concrete with close characteristics as normal concrete beyond age 28-days.
- The compressive strength of samples increases with increase in hydration period.
- Water absorption and simultaneous loss in materials results in the reduction of density of samples although, a linear pattern for the slight loss in density was recorded due to saturation of all the concrete specimens over the entire extended hydration periods.
- The introduction of RHA presents a good tendency of pozzolanic activity.
- Over the extended periods, considerable drop in compressive strength of samples cured for 56-90days was noticed in association with RHA contents not utilized in the pozzolanic reaction.
- This paper demonstrates how abundant available and cheap agricultural waste can be transformed into a useful resource. Hence, extended hydration periods of up to 150-days can produce RHA/OPC concrete with sufficient strength for structural works.

Acknowledgment

The authors wish to thank the Federal University of Technology, Minna and Abia State Polytechnic, Aba where the initial stages of this work were done and the University of Johannesburg, South Africa where the later stage of this study was completed.

References

[1] Elinwa, A.U. and Mahmood, Y.A. (2002), Ash from Timber Waste as Cement Replacement Material, *Cement and Concrete Composites*, V. 24, No. 2, pp. 219-222.

[2] Al-Ani, M. and Hughes, B. (1989), Pulverized-fuel ash and its uses in concrete, Mag. Concr. Res.41 (147) pp. 55–63.

[3] Swamy, R.N. (1986), Cement Replacement Materials, Concrete Technology and Design, Surrey University Press, Great Britain.

[4] Berry, E.E. and Malhotra, V.M. (1980), Fly ash for use in concrete - a critical review, J. of ACI 77 (8), pp. 59–73.

[5] Bilodeau, A. and Malhotra, V.M. (2000), High volume fly ash system: concrete solution for sustainable development, ACI Mater. J, 99 (1), pp. 41–48.

[6] Khandaker, M. and Anwar H. (2002), "Blended cement using volcanic ash and pumice".

[7] ECO-CARE Education, (2005), Building Material: Composition of Ordinary Portland Cement. http://www.ecocareeducation.com /building_material.htm.

[8] Matawal, D.S. (2005), Application of Ashes as Pozzolana in Mortar and Concrete Production, *1st National Academy Conference*, 31st August - 2nd September.

[9] Ujene, A.O. and Achuenu, E. (2005), The Compressive Strength of Concrete Containing Varying Proportions Selected Locally Sourced Aggregates in Nigeria, *International Journal of Environmental Issues*, Vol.3, No.1, pp. 81-87.

[10] American Society for Testing and Materials, *Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete*, ASTM C 618, 2008.

[11] Job, O.F. (1998), The Relationship between the Strength and Non-Destructive Parameters of Pulverized Burnt Clay Concrete, *Journal of Environmental Sciences (JOES)*, Vol. 1, No. 2, pp. 9 (57 -64).

[12] Neville, A.M. (2006), *Properties of Concrete*, 4th Edition, copyright © 2000, Asia, Person Education Pte. Ltd.

[13] Popovics, S. (1998), What Do We Know about the Contribution of Fly Ash to the Strength of Concrete, *Proceedings of 2nd International Conference, ACI Special Publication SP-91*, Malhot. V.M. ed., Detroit. Mich, 1986, pp. 313 -332.

[14] Shetty, M.S. (2004), *Concrete Technology – Theory and Practice*, New Dhelhi, India, S. Chand and Company Limited,

[15] Ikpong, A.A. (1993), The relationship between the strength and Non destructive parameters of Rice husk ash concrete, cement and concrete Research 23, pg, 387-398 London: cement and concrete Association.

[16] Varghese P.C. (2006), Building Materials, New Delhi, Prentice – Hall of India.

[17] Okpalla, D.C. (1987), Rice Husk Ash as a Partial Replacement for Cement in Concrete, Proceedings of the Annual Conference of the Nigerian Society of Engineers, Port Harcourt, Nigeria, pp. 1-12.

[18] Nagataki, S. (1994), Mineral Admixtures in Concrete: State of the Art and Trends. Special Publication, *Materials Journal* 144: 447-482.

[19] TMH1. 1986. *Standard Methods of Testing Road Construction Material*, Technical Methods for Highways. Vol. l1.