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Transformation and Utilization of Agricultural Waste as Component of Green Concrete for Rural Housing and Development Schemes

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Abstract. Several researchers have outlined cost saving and cement blending merits without compromising standards. As such, utilizing artificial pozzolana as supplementary cementitious materials (SCMs) in concrete engineering is well known. However, there is continual search for substitute materials. The use of Rice Husk Ash (RHA) as cementitious constituent in green concrete was studied. Its abundance paved way for the study to look into the compressive strength of the concrete type formed by partly substituting Ordinary Portland Cement (OPC) with RHA under short curing series. Analysis on RHA revealed significant properties of pozzolanic hardening. 60 cubes of 100 mm dimensions were cast with cement replacement by RHA ranging from 0-40% while adopting a 28 day targeted strength of 25 MPa as control. The cubes were cured at relative humidity (RH) of 95-100% and temperature (T) of 22-25 ^{0}C in a chamber for periods of 7, 14, 21 and 28 days. The outcomes displayed trends of strength gain, reduced density and compressive strength with increase in RHA. The 28 days density and strength of the normal concrete was 2465 kg/m^3 and 28.57 MPa while the 10% RHA sample (i.e. best substitute matrix) had 2398 kg/m^3 and 25.97 MPa respectively. The strength of 10% RHA/OPC concrete (25.97 MPa) was slightly higher than the adopted strength (25 MPa) at 28 days. This signifies its suitability as concrete constituents and can be a major cost reduction factor in rural shelter projects where less structural complexities are required. Hence, it can be employed in the construction of simple foundations and concrete composites.

Keywords: Rice Husk Ash (RHA), pozzolana, compressive strength, agricultural waste, density

1. Introduction

The generation of supplementary cementitious materials (SCMs) is vital to developing countries as low-cost construction constituents in self-sustaining means of shelter. The unrelenting rise in the prices of conventional materials has triggered the search for locally available resources as alternatives. These alternatives are to supplement the costly conventional materials partly or fully particularly in mortar and concrete. The use of SCMs as observed by [1] does not only improve concrete properties but protects and conserves the environment by saving energy and natural resources and also lowering the carbon footprint. Thus, studies by [2], [3] addressed waste ash suitability as options in concrete production. Inert fillers in are acceptable as cement substitute used in controlled quantities. Their pozzolanic properties as stated by [4] give technical advantages and larger quantities of cement substitution. Larger portions of the cement used in construction is the OPC manufactured by mixing naturally occurring substances containing calcium carbonate with substances containing alumina, silica and iron oxide [5]. PC blended with fly ash (FA) and silica fume (SF) are generally accepted while OPC blended with artificial pozzolana like sugar cane ash

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(bagasse) and burnt oil shale are utilized in regions where they are known. In pozzolana the amorphous silica present combines with lime to form cementitious materials. These materials improve durability of concrete, rate of strength gain and reduces rate of heat of hydration which in turn benefits mass concrete. Researches are geared toward wholly or partially substituting locally available pozzolana like saw dust ash, millet husk ash, pulverized fuel ash, corn cob ash etc., in concrete [6], [7]. In this paper however, investigated the effect of partially merging locally available RHA with cement on the strength characteristics of the concrete product under short term chamber curing. The addition of RHA (a seemingly unsightly idle agricultural waste) into concrete is an option to harnessing agricultural waste as constituent of an affordable and functional green produce. The 28 days strength is used in the investigation as trial assessment of pozzolanic activity in consonance with [8].

2. Review of Related Works

2.1. Locally Available Pozzolana

Works of researchers like [9], [10] in replacing cement with locally available pozzolana are well established. “Pozzolana” is defined as naturally occurring and artificially siliceous or siliceous and aluminous materials which in themselves have little or no cementitious properties. However, in finely divided form and water is introduced, react with calcium hydroxide expelled during the hydration of OPC at normal temperatures to give compounds possessing sufficient binding properties [10], [11]. Trends on alternative and locally available materials have concentrated on partial or total substitution of cement in concrete, showing that pozzolana can produce concrete with similar properties as normal concrete at age 28 days and longer. Rice is a cereal grain which forms the most important staple food for a larger part of the world's population. It is a grain with the second-highest worldwide production after maize (corn). Rice husk is the outer covering of the rice grain as per [12]. It consists of two interlocks and it is a vast agricultural waste usually generated in tonnes during manual or mechanical threshing (as in Fig. 1). Rice husk is a finely divided particle of agricultural waste measuring less than 1/9 mm in diameter as defined by [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 subtropical areas it survives as perennials and can produce a ratoon crop for up to 30 years. This indicates its availability as an industrial raw material as a result of enormous consumption rate. RHA is however obtained after burning the husk in a controlled furnace ensuring the temperature is maintained between ranges of 650-700^{o}C to produce highly reactive amorphous ash nodules/clinkers as shown in Fig. 2 in conformance to [12].

Fig. 1: Rice husk (agricultural disposed as waste)

Fig. 2: Rice husk clinks

RHA as recorded by [14] is 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 controlled burning conditions and its colour relies on the carbon content of the ash. Highly amorphous pozzolanic ash is gotten from controlled incineration temperature range of about 700^{0}C. Applications of various ashes as optional cement substitutes in mortar and concrete have drawn the attention of researchers. These optional constituents do not only contribute to improvement of concrete performance (i.e. increased strength, durability and reduction of heat of hydration) but also reduces energy and carbon emission from cement producing plants. Thus, 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 widely investigated [6].

3. Materials and Method

3.1. Experimental Procedure

The Rice Husk used in this investigation was gotten 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 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 ash as shown in Fig. 3 was formed by crushing the clinkers and passing them through the 75 μm sieve. RHA chemical content determined by x-ray diffraction (XRD) and r-ray fluorescent (XRF) method are shown in Table I 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% specified in [8]. As such indicates RHA to have appreciable pozzolanic tendencies. RHA/OPC mix ratios ranging from 0-40% substitutes (produced in triplicates) were tested. The control specimen (i.e. normal concrete) was proportioned for a targeted strength of 25 MPa in conformance with British Mix Design (D.O.E) method been the required minimum strength for structural concrete in accordance to BS8110.

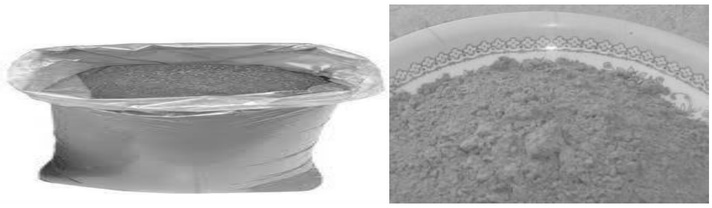

Fig. 3: Controlled incinerated RHA

Table I: Chemical constituents of RHA (%)

Chemical Composition	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	TiO	LOI	SiO_2+Al_2O_3+Fe_2O_3
RHA	2.72	66.2	6.95	4.03	2.61	-	15.9	75.87

The mix proportion used for this study was 1:2:4. “Dangote”, locally produced ASTM Type I Portland cement conforming to [15] 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. Properties from preliminary test results of constituent materials are given in Table II The fine aggregate used was sharp river sand free from dirt and injurious particles while the coarse aggregate was 19 mm (3/4in.) specific maximum size coarse aggregate which were obtained from “Dantata and Sowoe” Construction Company Nigeria Limited, Abuja. All the aggregates conformed to [16] and tap water was used for the concrete mixing while the curing process was done in a chamber. Effect of the various percentage replacements of RHA on the compressive strength characteristics and densities of green concrete were investigated over short term chamber curing. For the compressive strength to be determined 60 specimens of 100 mm cubic dimensions were cast and cured at a RH of 95-100% and T of 22-25^{0}C in a curing room for periods of 7, 14, 21 and 28 days. Permeable hessian bags were used to cover the samples and water was constantly sprinkled on the cover over the 7 days period through to the 28 days in accordance with [17]. At the end of every curing session, 3 specimens (as in Fig. 4) of each mix were crushed under direct loading from a compression test device and their averages were taken.

Table II: Physical properties of material constituents

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

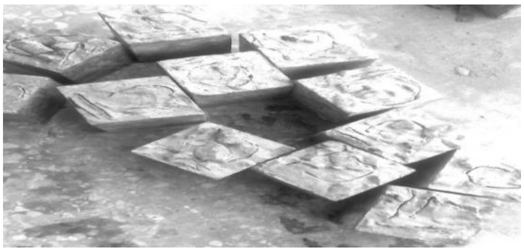

Fig. 4: Green concrete samples

4. Discussion of Results

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. At 28 days curing period 0%RHA substitute (i.e. control sample) had a density of 2465 kg/m^3 whereas 10%RHA substitute (i.e. best matrix) had a 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 28.57 MPa and 25.97 MPa respectively. Fig. 6 shows the compressive strength comparison between the control sample and the replacement matrices.

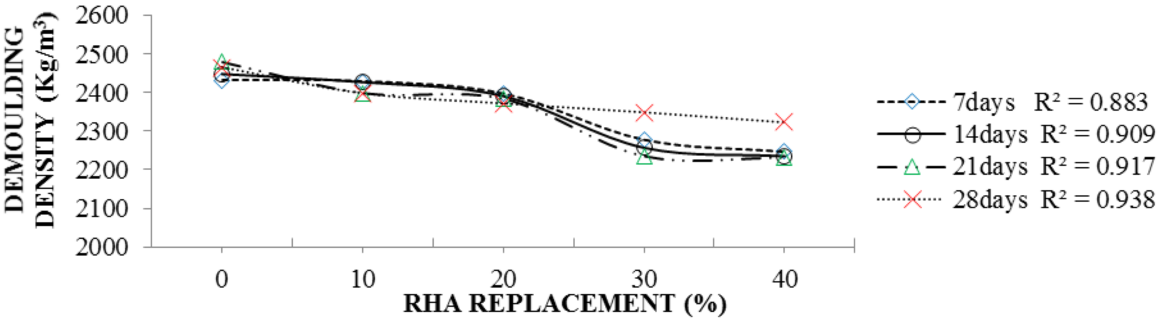

Fig. 5: Effect of RHA replacements on concrete density

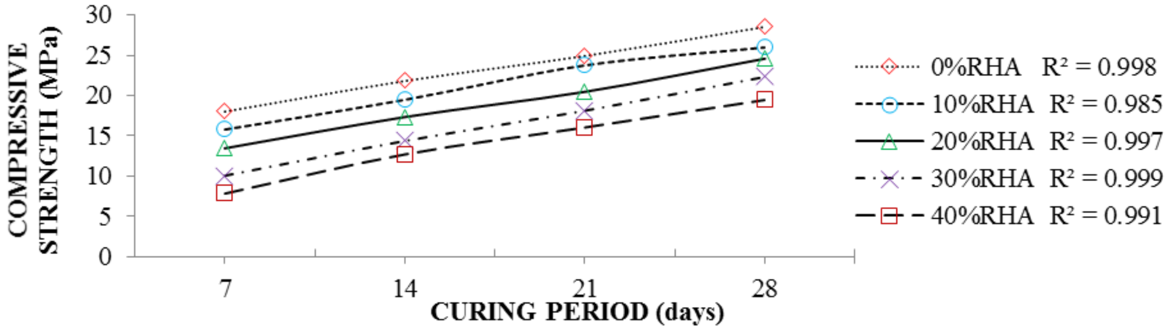

Fig. 6: Compressive strength of respective concrete samples

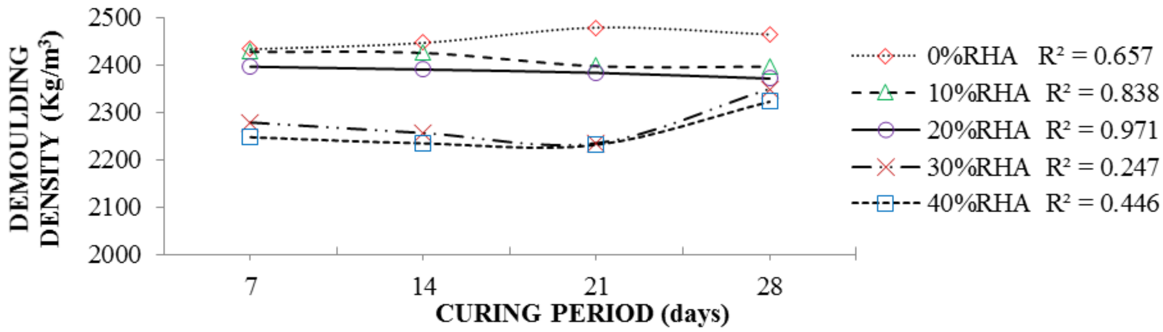

Fig. 7: Density of concrete samples with respect to curing ages

There is a strong correlation between the compressive strength and the curing periods. Although, the strength of cement blended with pozzolana improves with age since pozzolana react more slowly than cement due to difference in composition but obtain similar strength after about a year. However, the trend shows a gradual strength development of the green concrete as the curing age increases. 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 curing age. This can be accounted for due to water absorption and the simultaneous loss in materials caused by the effect of curing. 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 periods. 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, a fairly strong correlation between the concrete density and the curing period is observed. A strong correlation is 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 curing periods as shown in Fig. 8 can be due to excess idle amorphous silica and/or alumina from RHA not used up in the reaction. Hence, the excess RHA simply contributed to the loss in strength. For 28 day strength it therefore required as per [8] that the limit to which cement be replaced for quality and economy should be 20%.

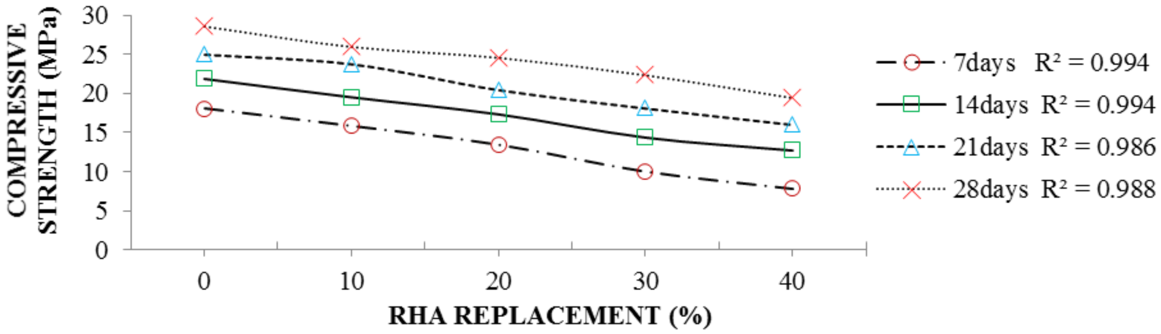

Fig. 8: Effect of RHA replacement on compressive strength of concrete

5. Conclusions

The study investigated the transformation and utilization of RHA as a form of agricultural waste towards the production of green concrete without compromising standards. The outcomes of the study revealed that the 10%RHA replacement (i.e. the best matrix) had 28 day strength of 25.97 MPa which was found to be lower than the strength of the control specimen of 28.57 MPa however, was above the targeted strength of 25 MPa. As such, satisfies the minimum strength for structural concrete specified by BS8110. Furthermore, the strength of green concrete samples were found to increase with increasing curing 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 curing ages significant loss in strength of samples was recorded due to RHA quantities that were not utilized in pozzolanic reaction. This paper therefore demonstrates how the use of RHA is yet another option in transforming abundantly available cheap agricultural waste into useful resource for developing countries. Hence, the green concrete product can at the moment be utilized in the construction of simple foundations and masonry walls while further investigations are recommended to be carried out for extended hydration periods of up to 120 days to ascertain the pozzolanic tendencies, strength and durability of this new concrete product.

6. Acknowledgement

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