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PERFORMANCE OF RICE HUSK ASH AND HYDRATED LIME BASED MORTAR

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ABSTRACT

Over the time, mortar has been a key element in building construction and its overall relevance in virtually all civil engineering practice and building construction works cannot be over emphasized. Cement being one of the major components of mortar is among the three major producers of carbon dioxide which has been acclaimed to be the major greenhouse gas. The construction industry is in search of an effective agricultural/industrial waste product that would considerably minimize the use of cements and ultimately reduce its effect on the environment. This article reports on a study carried out on the performance of rice husk ash (RHA) and hydrated lime (HL) based mortar. The mortar mix was prepared using, 60/40, 50/50, 40/60 for RHA/HL proportions for this research. The consistency test of the binder, specific gravity and sieve analysis of fine aggregate were determined. The compressive and tensile strength test of the mortar specimens were evaluated. The results indicates that the average compressive and tensile strength of the mortar containing control specimen is higher as compared to those containing RHA/HL. Similarly, the compressive and tensile strength development of the mortar containing RHA/HL decreases with increased in the percentage increase of HL. However, Mortar with 40/60% RHA/HL shows a relatively adequate strength and therefore considered as the optimum percentage of the binder.

Keywords: Rice husk ash (RHA), Hydrated lime (HL), Compressive strength, Performance, Tensile strength

INTRODUCTION

Over the years the Conversion of wastes to wealth is gaining popularity all over the world. The use of agricultural waste for the manufacture of building materials is an effective way to reduce the consumption of material resources and at the same time, significantly reduce the effect of negative environmental impact (Claudiu & Nicoleta, 2013). Mortar is a construction material that consists, in its most common form, of Portland cement, fine aggregates, and water. Cement is one of the major components of mortar and in the most general concept of the word, is a binder, a substance with adhesive and cohesive properties which sets and hardens independently and binds other materials together into a compact whole (Neville & Brooks, 2010). Cement industry is one of the three major producers of carbon dioxide which has been advocated to be a major greenhouse gas. It has been reported that the production of one ton of cement generates approximately one ton of CO_2 directly and indirectly (Khan *et al.,* 2011).

The effect of global warming and climate change caused by the emission of carbon dioxide into the atmosphere from the production of cement and the pollution of the environment caused by agricultural waste deposits, calls for the need of concrete technologist seeking alternative cementing materials in form of pozzolanas in other to ensure a sustainable environment.

Pozzolan is a material which contain active silica (SiO_2) and is not cementitious in itself, but will, in a finely divided form combine chemically with lime in the presence of water at ordinary temperatures to form a strong cementing material (Neville & Brooks, 2010). They include: fly ash, volcanic ash, burnt shale, ash from some burnt plant materials (such as rice husk ash) and siliceous earths. Pozzolanic reaction is the chemical reaction that occurs in hydraulic cement, it refers to the process in which a siliceous material reacts with the calcium hydroxide ($Ca(OH)_2$ or represent by CH) content in the concrete in the presence of water to form C-S-H gel (Papadakis *et al.*, 2002). According to Papadakis et al., (2002), Calcium silica hydrate (C-S-H) and CH are formed in the hydration of two main compounds of cement which are tricalcium silicate (C_3S) and dicalcium silicate (C_2S). The Pozzolanic process may be written as:

$$2(3CaO_2SiO_2) + 6H_2O \rightarrow 3CaO_2SiO_23H_2O + 3Ca(OH)_2 \quad \text{(Eq. 1)}$$

$$2(2CaO_2SiO_2) + 4H_2O \rightarrow 3CaO_2SiO_23H_2O + 3Ca(OH)_2 \quad \text{(Eq. 2)}$$

$$2SiO_2 + 3Ca(OH)_2 \rightarrow 3CaO_2SiO_23H_2O \quad \text{(Eq. 3)}$$

Rice is an important staple food for approximately half of the world population (Slayton & Timmer, 2008). Various researchers have studied the physical and chemical properties of rice husk ash and established that even though RHA alone lacks cementitious properties, the high percentage of siliceous material in RHA is indication that it has potential Pozzolanic properties (Waswa-sabuni *et al*, 2002).

Chandrasekhar, et al [2003], verified further that when RHA is used as filler in concrete and mortar blocks, the strength is enhanced due to its Pozzolanic property. RHA has been used in lime-pozzolana mixes and could be a suitable partly replacement for Portland cement (Smith & Kamwanja, 1986; Zhang & Mohan., 1996; Nicole *et al.,* 2000; Sakr., 2006; Sata, Jaturapitakkal & Kiattikomol, 2007)

The addition of pozzolana decreases the formed CH crystal by the Pozzolanic reaction to produce more C-S-H gel that can improve the strength and durability of concrete (Azzez, Aleem & Heikal, 2005).

Cement replacement by RHA accelerates the early hydration of C_3S, the increase in the early hydration rate of C_3S is attributed to the high specific surface area of the RHA (Feng *et al.,* 2004). This phenomenon specially takes place with fine particles of RHA. Although the small particles of pozzolanas are less reactive than Portland cements (Mehta & Aitcin, 1990), they produce a large number of nucleation cites for the precipitation of the hydration products by depressing in cement pastes.

Hydraulic lime, being one of the oldest binders contributes substantial history in construction practices and manufacturing (Grist, et al 2015). Hwang, Noguchi & Tomosawa, (2004) reported that the addition of lime powder as a replacement of fine aggregate in concrete resulted in higher compressive strength due to the reduction the pore structure. Abalaka & Okoli (2013); studies the "Comparative Effects of Air and Water Curing on Concrete containing Optimum Rice Husk Ash Replacement".

This paper focuses on the performance of rice husk ash (RHA) and hydrated lime (HL) as binders in mortar production. It evaluates the fresh properties of the mortar and also effect on its compressive strength and tensile strength. It seeks to compare the behaviour, properties and characteristics of mortar produced with various proportion of the rice husk ash and hydrated lime blend.

Experimental Program

Materials

The materials used in this study include; rice husk, hydrated lime, natural river sand, Portland cement and water.

The cement used was ordinary Portland cement (OPC), CEM II-42.5N. The cement was sourced from cement from supplier. The properties of the cement were in accordance with BS EN 197 - 1 (2000).

The rice husk used was sourced from rice mill located at Minna, Niger State, Nigeria. It was sun dried and kept in waterproof bags. The Rice husk was burnt under uncontrolled temperature using the incinerator to generate RHA needed for the investigation. The burnt ash was heaped and left to cool for 24 hours, which is sufficient to turn most of the burnt ash into white ash (amorphous material). The white ash was then ground for several minutes using a laboratory ball mill.

Thereafter it was grinded and sieved using the 75µm BS sieve. Thus, the ash passing through the sieve was used for the investigation.
The hydrated lime used was sourced from building material market Minna, Niger state. It was oven dried for 24 hours and grinded for fineness after which it was sieved using the 75µm BS sieve.
The water used for this research was free of algae, spirogyra and other biological substances which conformed to BS EN 1008 (2002).
The sand used for this research is a good quality sharp sand locally purchased from supplier and conformed to the requirements of ASTM C33 (2003).

Methods
The consistency test which include the determination of the setting time (initial and final), the water demand of the RHA, HL and cement paste were done in accordance with BS EN 196-3 (2016).
The sieve analysis of the fine aggregate was performed in accordance with ASTM C33 (2003), while fine aggregate passing through the 4.75mm sieve size was used for this research.
Specific gravity is the ratio of mass of a unit volume of a material to the mass of the same volume of water at the same temperature. The specific gravity of the cement, RHA and HL used for this study were determined in accordance with BS EN 932- 1 (1997).
The fresh properties of mortar in terms of workability was measured using flow ability of mortar in accordance with ASTM C1437 (2001). The hardened properties (compressive and tensile strength test) were performed on the mortar according to ASTM C109 (2013).
The desired design of mortar mix employed was 1:3 and summarized in Table 1. The mix design was based on weight proportioning of the mortar constituents.

Table 1: Mix design of the Mortar specimens

Mortar Designation	RHA (g)	hydrated lime (g)	fine aggregate (g)	cement (g)	water (g)
Control (0)	-	-	11250	3750	2326
60/40	2250	1500	11250	-	3720
50/50	1875	1875	11250	-	3392
40/60	1500	2250	11250	-	3116

Casting and curing of specimen
In casting the mortar cubes, the mix ratio employed was 1:3 with constant water cement ratio of 0.5. The freshly mixed mortar was scooped into the mould of dimensions 50x50 x50 mm for the compressive strength and 45x90 mm for the tensile strength test were compacted mechanically by the use of an electric vibrator in three layers. The specimens were cured in water for compressive and tensile strength at 3, 7,14,21,28 and 56 days

RESULTS AND DISCUSSION:
The test results include, the physical properties of the materials, consistency test of binders, chemical composition of the binders, compressive and tensile strength of samples.
Sieve analysis of fine aggregate
Fig. 1 shows the particle size distribution of the fine aggregate (river sand) used in producing the mortar specimens. The particle size distribution indicated that fine aggregate is fine particles and fall to medium grade quality of BS 882 (1992) standard. The result also shows that the fine aggregate has a fineness modulus of 2.64, which is within the range of 2.3 - 3.1 of ASTM C33 (2003) standard.

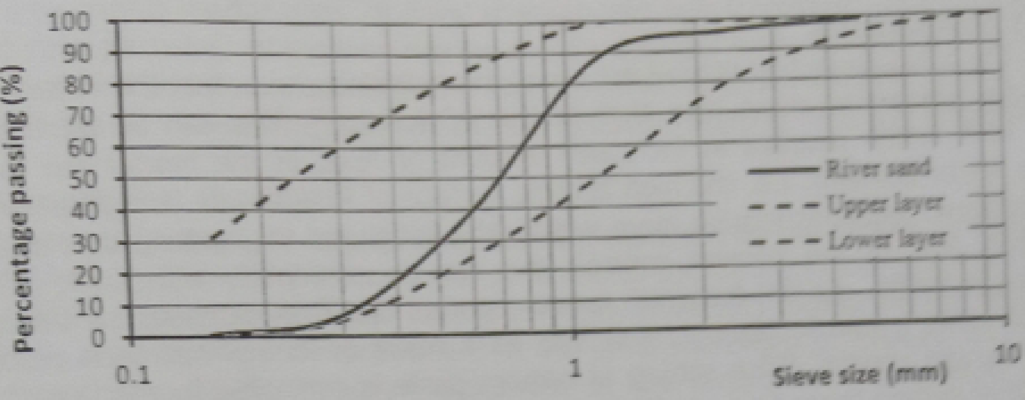
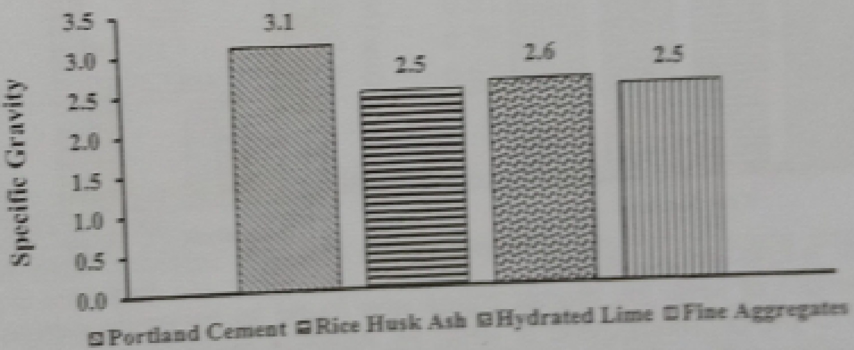


Fig. 1: Particle Size Distribution

Specific gravity

The specific gravity test result of the various material used for the research are presented in Fig. 2. From the result, the specific gravity of cement was 3.1, hydrated lime was 2.6 while both rice husk ash and fine aggregate has 2.5. This lower specific gravity of the agro-industrial waste binders is responsible for the lower densities of the mortar specimens produced from these respective binders.



Chemical Composition of materials used

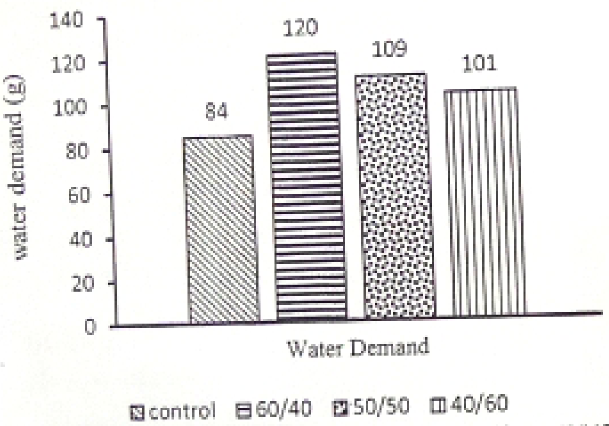
The result obtained from the oxide composition test of the PC, RHA and HL samples were conducted at Lafarge cement industry, Ewekoro, Ogun state and presented in Table 3. The RHA result shows that the arithmetic combination of its SiO_2, Fe_2O_3 and Al_2O_3 gives a total 95.5%. This shows that RHA fall to class N pozzolana of ASTM C618 – 12a (2013) standard which stipulate that the combined oxide content should be 70% and above. The presence of Silica (SiO_2), Iron Oxide (Fe_2O_3,) and Alumina (Al_2O_3) in the RHA are responsible for the formation of cementitious compounds when they react with lime. The chemical properties of the RHA show only minimal presence of Sulphates (SO_3) content of 0.2% which is within the maximum content of 5% as per ASTM C618-2016 specification. This Sulphates (SO3) causes formation of secondary ettringite (calcium sulfoaluminate) mortar leading to its expansion and rupture, thus its low presence makes the RHA good for mortar production.

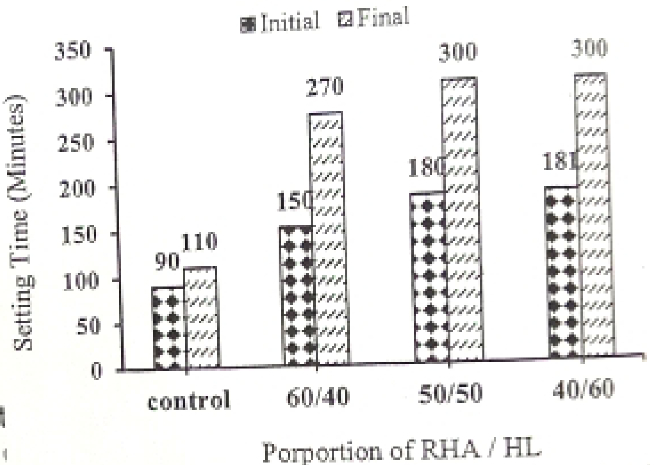
Table 3: Chemical Composition of Materials

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	LOI	So_3	Tio_2	Ar	Sr	C_3A	Mn_2O_3
RHA	93.6	1.1	0.9	1.3	1.2	0.2	1.7	-	0.2	0.1	1.2	49.3	-	-
HL	1.3	0.4	0.2	90	1.0	0.9	1.29	-	-	-	-	-	-	0.03
Cement	34.73	8.49	4.80	35.56	1.62	2.06	1.25	-	1.87	-	-	-	7.49	-

Consistency Test Results

The result of the consistency test carried out on all the materials shows that the water demand for the new binder paste was more than that of the PC (control). This can be attributed to the presence of RHA which resulted in increased amount of fines in the mortar mix and hence, increases the water demand. I.e. the high specific surface of RHA results in high water demand. Also lime pozzolanic reactions require more water. The initial and final setting time of the binder was more than that of the cement control, this was in conformity with Cook (1986), and Bhanumathidas & Mehta. (2004) for which it was reported that RHA increases the setting time of paste just like other hydraulic cement. This was as a result of its low hydration process when compared to cement control. Since setting of cement paste is controlled by reaction of C_3A with water, the higher setting times found in the binder could be due to the low quantity of alumina in the RHA. Invariably, the hydration process of the binder increases with increase in amount of RHA content, this indicates why there was a gradual increase in the setting time as the RHA content reduces. The various results from the test are summarized in Fig. 3 & 4.





Compressive strength of RHA: HL mortar mixes was found to generally increase with increased amount of HL until the optimum blend of RHA: HL 40:60 is reached. Below the optimum blend, there is not adequate calcium hydroxide $Ca(OH)_2$ available to react with the Silica, Alumina and iron oxide in the RHA. Therefore, as the HL content increases, more cementitious products such as calcium silicates and calcium aluminates are formed thus increasing the compressive strength of the concrete. At the optimum blend, it is expected that the amount of silica, alumina and iron oxide in the RHA is adequate to react with all the available calcium hydroxide $Ca(OH)_2$. Any amount above the optimum mix, which resulted in the reduction of available CaO and reduced the amount of $Ca(OH)_2$ available for reaction with Silica, Alumina and Iron Oxide in the RHA. This led to reduced amount of C-S-H compound within the mix and might have caused the reduction of strength beyond the optimal blend.

Table 4: Compressive Strength of RHA/HL Mortar

	Curing ages					
	3 days	7 days	14 days	21 days	28 days	56 days
Mortar Designation	CS (MPa)	CS (MPa)	CS (MPa)	CS (MPa)	CS (MPa)	CS (MPa)
Cement Control	8.56	12.20	14.12	16.26	21.24	25.36
60/40 (RHA/HL)	1.05	1.36	1.39	1.50	1.55	1.69
50/50 (RHA/HL)	1.65	2.03	2.21	2.36	2.46	2.51
40/60 (RHA/HL)	1.66	2.25	2.40	2.47	2.54	3.31

The result was further observed that the compressive strength of control specimen was considerably higher than that of RHA:HL binder, however Ana, Nuno & Augusto, (2010) studied the effect of rice husk ash particle size in lime based mortars. From their result the compressive strength of lime control mortar after 28 days' strength test was 0.5N/mm². The comparison of the compressive strength values of the lime mortar and the mortars formulated with RHA:HL allows us to conclude that RHA revealed a considerable reactive. This increased strength is as a result of the formation of hydraulic compounds, such as calcium silicates resulting from the pozzolanic reaction.

Tensile Strength Test Results:

Table 5 shows tensile strength results. The results indicated that the tensile strength decreased sharply in RHA:HL specimens. This could be attributed to the CaO and formation of more calcium hydroxide $Ca(OH)_2$, which reduced the tensile strength. However, comparing the results at 7 and 56 days, there is an significant improvement in the tensile strength of RHA:HL mortar mixtures. The stronger cement bonds of mortar specimens in the control tend to gained more tensile strength than RHA:HL mortar specimens.

Table 5: Tensile Strength of RHA/HL Mortar

	Curing ages					
	3 days	7 days	14 days	21 days	28 days	56 days
Mortar Designation	TS(MPa)	TS(MPa)	TS(MPa)	TS(MPa)	TS(MPa)	TS(MPa)
Cement Control	2.8	3.17	3.42	3.85	4.78	5.63
60/40 (RHA/HL)	0.20	0.46	0.51	0.57	0.76	0.90
50/50 (RHA/HL)	0.17	0.30	0.39	0.43	0.58	0.63
40/60 (RHA/HL)	0.22	0.57	0.63	0.71	0.80	0.94

CONCLUSIONS

The following findings were concluded from the tests conducted on performance of rice husk ash and hydrated lime based mortar:

1. The result presented revealed that the cement mortar developed more strength that the RHA/HL mortar.
2. The results of chemical composition tests indicated that the RHA is a good pozzolanic material for use in mortar production, with a combined percentage of Silica (SiO_2), Iron Oxide (Fe_2O_3,) and Alumina (Al_2O_3) of more than 70%.
3. The average compressive and tensile strength of the mortar containing cement is higher as compared to those containing RHA/HL. Similarly, compressive and tensile strength development of the mortar containing RHA/HL decreases with increased in the percentage of HL. However, Mortar with 40/60% RHA/HL shows a relatively adequate strength and therefore considered as the optimum percentage of the binder.
4. The water demand of the cement paste was found to be lower than those of the RHA/HL binder, also the water demand of the RHA/HL increases with increased in the percentage of the RHA content.
5. The initial and final setting time of the cement mortar was lower than that of the RHA/HL binder, consequently the initial and final setting time of the RHA/HL binder increases with increased in HL proportion.
6. The mortar specimen of 40/60 mix can be classified as classified as type O mortar because the maximum strength was above 2.4 N/mm² with respect to BS EN 998-2 (2003) and could be used for rendering of non-load bearing walls.

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