Investigation of Rice Husk Ash Cementitious Constituent in Concrete

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Abstact This research evaluates rice husk ash (RHA) as a cementitous constituent in concrete productions. Raw rice husk obtained from rice mill situated in Ilorin metropolis, Kwara State, Nigeria was burnt in a furnace at a controlled temperature of $700^{o}C$ for a period of four hours. The ash was analysed for its physical and chemical properties. The mechanical performance of the ash in the concrete was investigated when used as a partial replacement for cement in concrete at 10%, 20% and 30% respectively with a control test that contains 0% RHA. Experimental findings showed that the RHA can be categorized as N-class pozzolana according to ASTM C618-12. The workability of the concrete falls as the RHA content increases. It was also observed that the compressive strength of Rice Husk Ash Concrete *(*RHAC*)* increases with curing age but decreases as the percentage of cement replacement with ash increases. The density of the concrete produced also reduces even with age as the percentage replacement of cement with ash increases. The optimum compressive strengths of RHAC are 25.80 N/mm^2, 22.73 N/mm^2 and 19.6N/mm^2 while the corresponding densities are 2449.67Kg/m^3, 2348.33Kg/m^3 and 2265.67Kg/m^3 respectively at 10%, 20% and 30% at 28 days curing age when compared with the control test which is 27.47 N/mm^2 and 2517.67 Kg/m^3. These values for RHAC produced can therefore be used for reinforced concrete with either normal or light-weight aggregates. This will not only improve the quality of the concrete but also reduce drastically burning of agricultural waste that causes environmental pollution.

Keywords: Pozzolana, RHA, compressive strength, environmental pollution, workability

Introduction

Rice husk (RH) is the outer layer covering of the rice grains that is obtained during the milling process. This is usually being thrown away to the landfill without further use, thus, contribute to environmental pollution. RH constitutes 20% of weight of the total rice produced and the husk composed of 28 - 38% of cellulose, 9 - 20% of lignin, 18.80 - 22.30% of silica and 1.9 - 3.0% of protein (Anbu and Nordin, 2009). Rice husk ash (RHA) is a by-product

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from the burning of rice husk under controlled temperature and burning time. RH has been used as a highly reactive pozzolanic material leading to a significant improvement on strength and durability of normal concretes (Bui, 2001). It is extremely prevalent in East and South-East Asia because of the rice production in these areas (Nick, 2009). Also, rice constitutes one of the major crops produced in Nigeria. Statistics have shown that it is the fourth major cereal in Nigeria after sorghum, millet and maize in terms of output and cultivated land area. It is a major staple and most popular cereal crop of high nutritional value grown and consumed in all ecological zones of the country. The average Nigerian now consumes about 24.8 kg of rice per year representing 9% of the total calories intake. In spite of its contribution to the food requirements of the Nigerian population, rice production in the country is put at about 3.2 million tonnes (Babafada, 2003).

Disposal of the husks is a big problem and open heap burning is not acceptable on environmental grounds, and so the majority of husk is currently going into landfill. These are utilized as fuel in some regions, while they are regarded as wastes in other regions causing environmental pollution. When burnt under controlled conditions, the RHA is highly pozzolanic and very suitable for use in lime-pozzolana mixes and for Portland cement replacement (Yogenda and Jagadish, 1974). Otherwise, the ash which is essentially silica will be converted to crystalline forms and becomes less reactive. It has been tested and found that the ideal temperature for producing excellent results is between 600 °C and 700 °C (Nick, 2009). In line with (Sima, 1974) definition, Rice husk has been recognized as pozzolona because siliceous and aluminous materials in has little or no cementitious value, but in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide liberated during the hydration of Portland Cement to produce stable, insoluble cementitious compound which contributes to its strength and impermeability. RH has a high concentration of silica, generally between range of 80-85% (Siddique, 2008).

Researchers have shown that small amounts of inert filler have always been acceptable as cement replacement. Silica fume, fly ash, met kaolin, palm kernel ash, sugarcane bagasse ash and ground granulated blast furnace slag are well established wastes with pozzolans. (Megat *et al*., 2008) investigated the effect of silica fume, metakoalin, fly ash and granulated blast fume on workability, compressive strength, elastic modulus and porosity of high strength concrete.

Some of the advantages of using pozzolans in concrete includes improvement in workability of concrete at low replacement levels and with low carbon content, reduced bleeding and segregation, low heat of hydration, lower

creep and shrinkage, high resistance to chemical attack at later ages (due to lower permeability and less calcium hydroxide available for reaction) and low diffusion rate of chloride ions resulting in a higher resistance to corrosion of steel in concrete. (Feng *et al*., 2004) found out that various metal ions in the husk and unburned carbon influence the purity and colour of the ash.

The chemical analysis of RHA obtained in Malaysia has 96.7% Silicon dioxide (SiO_2) with 0.91% of potassium oxide (K_2O), and has some minor oxides such as alkalis, sulphate and calcium oxide. The sum of these oxides i.e. $SiO_2 + Al_2O_3 + Fe_2O_3$ of RHA were 97.8% (ASTM, 1978). Thus, classified as pozzolan in accordance with American Standard for Testing Materials (Kartin, 2011) that specify 70% minimum for SiO_2. Controlled burning of the husk after removing these ions with an acid leaching can produce white silica of high purity that is amorphous, reactive, and characterized by high surface area and pore volume. Acid treatment has been found to decrease the degree of crystallization of silica and carbon in rice husks reducing the sensitivity of the pozzolanic activity of the rice husk ash to burning conditions. This study investigates the cementitious properties of RHA as partial cement replacement in concrete to come up with the optimum percentage replacement of RHA with cement.

Materials and methods

The materials used in this research work are rice husk, Ordinary Portland Cement (OPC), aggregates (fine and coarse) and water.

Rice Husk

This was collected from the rice mill situated at Oja-gboro in Ilorin metropolis, Kwara State, Nigeria.

Ordinary Portland Cement

Elephant cement which belongs to Ordinary Portland Cement family was used and is in accordance with BS (BS EN, 2000).

Fine Aggregate

This was sourced from a construction site in the university of Ilorin premises and is in accordance with BS (BS, 1992).

Coarse Aggregate

This was sourced from a construction site in the University of Ilorin premises. It is also in accordance with BS (BS, 1992).

Water

Clean and drinkable water which is clear from impurities and is in accordance with BS (BS, 2002). was used**.**

The rice husk was burnt at a temperature of about $700\,°C$ using a controlled blast furnace for a period of four hours. The burning was done at the Fabrication Workshop, Department of Mechanical Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin, Nigeria. Figures 1, 2 and 3 showed raw RH, processed RHA and the controlled furnace respectively. The burnt ash was grinded using mortar and pestle and was sieved using 0.09mm sieve. Chemical analysis of the processed RHA was carried out in the Chemistry laboratory, Department of Chemistry, University of Lagos, Lagos State, Nigeria (using Atomic Absorption Spectrophotometer) to determine the chemical composition of the ash. Physical test like water absorption capacity, particle size distribution, specific gravity, moisture content, fineness test were also carried out on the aggregates and the ash. Also, the design mix ratio for the concrete casting was calculated. This was used to cast concrete cubes of size 100mm x 10mm x 100mm at different RHA replacement level i.e. 0%, 10%, 20% and 30%. The cubes were cured for 7, 21 and 28 days at the room temperature of (27 ± 2) $°C$ and their corresponding compressive strengths were determined using a compressive strength testing machine. The densities of the concrete for different RHA replacement levels were also determined.

Fig. 1. Raw Rice Husk

Fig. 2. Processed Rice Husk Ash

Fig. 3. Controlled Blast Furnace

Results and discussion

Chemical Analysis of RHA

The results of the chemical analysis carried out on the processed RHA are presented on Table 1. From the table, the total sum of the percentage of SiO_2, Al_2O_3 and Fe_2O_3 is 90.71%. This satisfies the minimum percentage requirement for pozzolana when these constituents were added. Minimum of 70% is recommended according to ASTM C618 (ASTM, 1978) for any pozzolanic materials. The silica will enable the concrete to have good strength and durability while the alumina will make the concrete to be corrosion resistant.

Table 1. Chemical Composition of RHA

Parameters	Rice Husk Ash (%)

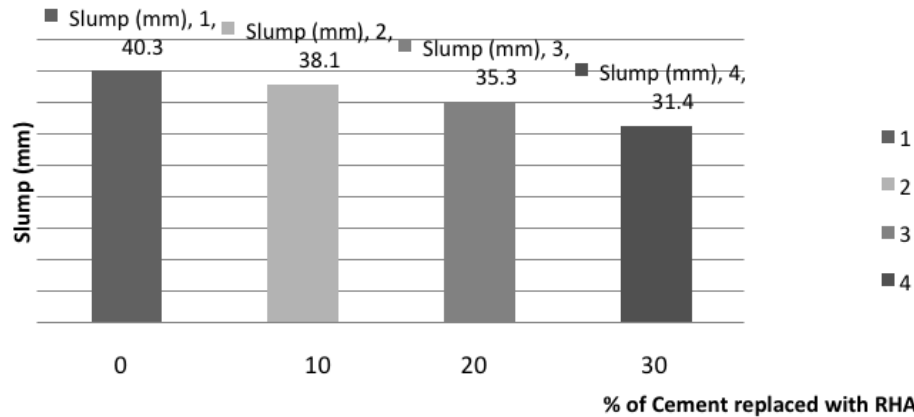|	
Silica (SiO$_2$)	77.267
Aluminium oxide (Al$_2$O$_3$)	3.592
Ferrous oxide (Fe$_2$O$_3$)	9.846
Calcium oxide (CaO)	8.947
Magnesium oxide (MgO)	5.849
Sodium oxide (Na$_2$O)	2.898
Copper oxide (CuO)	1.184
Loss of Ignition (LOI)	4.837
Potassium oxide (K$_2$O)	4.084

Estimation of the quantity of materials required for the production of concrete cubes for different RHA replacement levels and mix proportion of the constituents is as shown in Table 2.

Table 2. Estimate of the Quantity of Materials Concrete Cubes

% Replacement	Ash (kg)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	Quantity (Unit)	W/C Ratio
0	0	3.780	5.994	10.656	1.89	9	0.5
10	0.378	3.402	5.994	10.656	1.89	9	0.5
20	0.756	3.024	5.994	10.656	1.89	9	0.5
30	1.134	2.646	5.994	10.656	1.89	9	0.5

Slump Test

The result of workability of concrete (slump test) for 0%, 10%, 20% and 30% replacement of RHA are shown in the Figure 4. This shows that the height of the slump is reducing as the percentage replacement with RHA is increasing. The workability of fresh RHA concrete measured by the slump test reduces as the RHA content increases. This is due to the fact that, RHA absorbs more water to form a paste of standard consistency than cement.

Fig. 4. Slump Test Results

Mean Compressive Strength of Rice Husk Ash Concrete

For different cubes of concrete produced with various percentage replacement of cement with RHA, compressive strengths and densities were measured at different ages of curing and average computed**.** Table 4 shows the compressive strength test results for the various curing ages. Figures 5 and 6 showed variation of compressive strength for the various percentage replacement of RHA at different curing age. Figure 5 showed that the compressive strengths of the concrete are increasing as the curing age increases. Consequently, compressive strengths of the concrete are reducing as the percentage of RHA replacements are increasing in Figure 6. The compressive strength of 10%, 20%, and 30% replacement are 92.93%, 82.75%, 71.35% of that of the control at 28th day of curing respectively. The compressive strength were not up to the target mean strength designed for the concrete, this may be as a result of some factors like method of mixing (hand mixing), compaction, and added water to make the concrete workable. According to British Code CP 110: 1972 that specify the minimum strengths for various concrete, they are:

$7N/mm^2$ for plain concrete.
$15N/mm^2$ for reinforced concrete with lightweight aggregate.
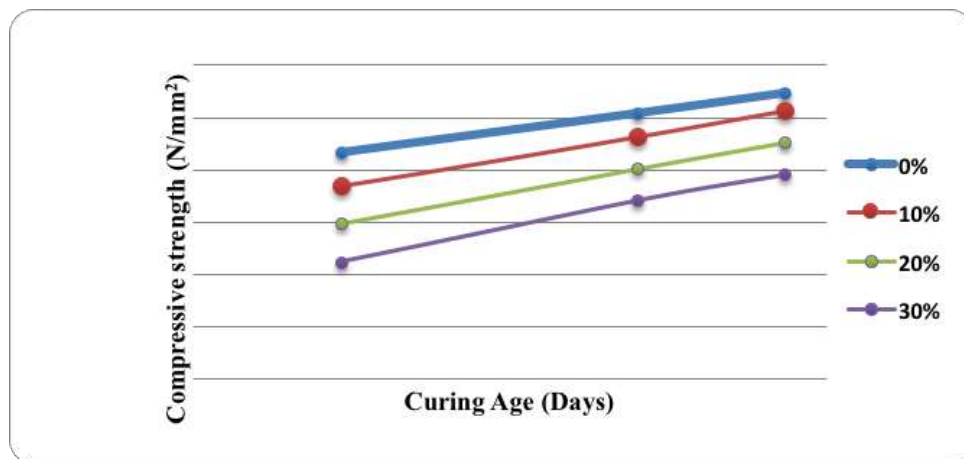$20N/mm^2$ for reinforced concrete with normal aggregate.
$30N/mm^2$ for post-tensioned concrete.
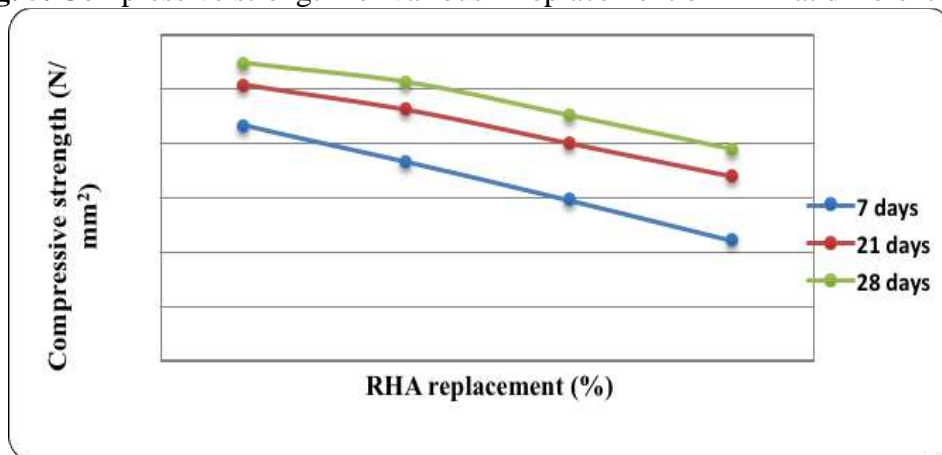$40N/mm^2$ for pre-tensioned concrete.

Therefore, the concrete produced with 10% and 20% replacement can be used for reinforced concrete with normal aggregate while that of 30% replacement is useful for reinforced concrete with lightweight aggregate.

Table 4. Compressive Strength for RHA Concrete at different Curing Ages in N/mm^2

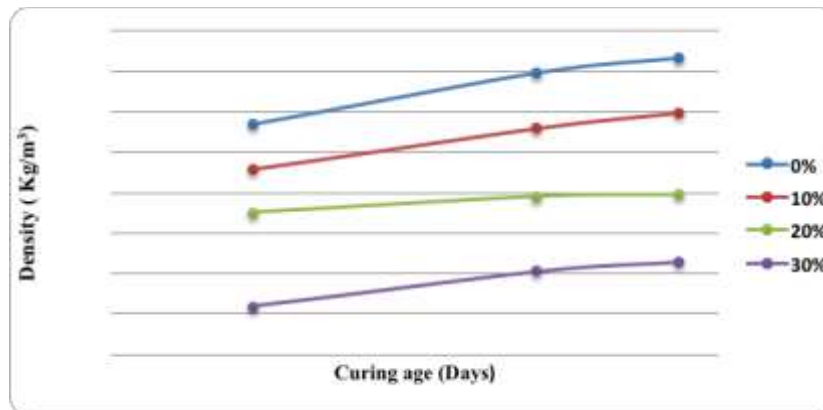| S/N	% Replaced	7 days	21 days	28 days
1.	0	21.80	25.53	27.47
2.	10	18.50	23.30	25.80
3.	20	14.93	20.20	22.73
4.	30	11.20	17.13	19.60

Fig. 5. Compressive strength for various %replacement of RHA at different age

Fig. 6. Compressive Strength with % RHA replacement at different curing ages

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The densities for the different percentage of replacement of cement with RHA at different ages of curing are as shown in Figure 7. This Figure showed that the densities of the RHA concrete fell into the range of 2226 - 2520 kg/m^3 at 28th day curing. Lightweight concretes can be produced with an oven-dry density range of approximately 300 to a maximum of 2000 kg/m^3 and the density for a normal concrete is 2240 to 2400 kg/m^3. With the conditions stated above, the concrete can be classified as normal weight concrete. Also, as the percentage replacement of OPC with RHA is increasing, the weights of the concrete cubes were reducing leading to a reduction in their densities.

Fig. 7. Densities for different % replacement of RHA at different age

Conclusion

From the study conducted, the conclusions can be made

It was clearly shown that RHA is a pozzolanic material that has the potential to be used as partial cement replacement material and can contribute to the sustainability of the construction material.

The calculated target mean strength of 31.56 N/mm^2 was not achieved. This may be as a result of some factors like mode of mixing (hand mixing), compaction, and the reactivity of the RHA.

The compressive strength of the concrete cubes increases as the curing age increases but decreases as the RHA content increases. The percentage reduction of compressive strength for 10%, 20% and 30% replacement of cement with RHA compared with control are 6.07%, 17.26% and 28.65% respectively.

Compressive strengths of the control i.e. 0%, 10%, and 20% RHA are 27.43 N/mm^2, 25.80 N/mm^2, and 22.73 N/mm^2 respectively. They all satisfied the minimum strength required for reinforced concrete with normal aggregate and they can be used for this type of concrete. For 30% replacement of cement with RHA, the compressive strength is 19.60 N/mm^2 and this can be used for reinforced concrete with lightweight aggregate.

From the density result, RHAC can be classified as normal weight concrete. The percentage reduction in density for 10%, 20% and 30% replacement of cement with RHA are 2.7%, 6.7% and 8.47% compared with the control respectively.

The workability of fresh RHAC measured by the slump test reduces as the RHA content increases.

There is an increase in setting time of paste having rice husk ash. This shows low level of hydration for rice husk ash concrete which result from reaction between cement and water, and consequently, liberate calcium hydroxide $Ca(OH)_2$.

Recommendations

RHA is a pozzolana and it is recommended for use as partial replacement for cement in concrete production at a percentage up to 20%. For environmental sustainability of concrete materials, RHA can be utilized for the production of lightweight, durable and cheap concrete because of it availability in significant quantities across the country.

References

American Standard for Testing Materials (ASTM). (1978). Specification for fly ash and raw or calcium natural pozzolana for use as a mineral admixture in Portland cement concrete. American Society for Testing and Materials 618-678.

Anbu, C. J. and Nordin, B. Y. (2009). Particleboards from rice husk: a brief introduction to renewable materials of construction. abadi group, Makmur Trading Business Centre, Kuala Lumpur, Malaysia, pp.12-15.

Babafada, M. (2003). Integrated rice production and export in nigeria. central bank of Nigeria, Hamadala, Hotel Kaduna, Nigeria. pp. 1-4.

Bui, D. (2001). Rice husk ash as a mineral admixture for ultra high performance concrete. (Master's thesis). Delft University of Technology, Delft, Netherlands. 138.pp.

Feng, Q., Yamamichi, H., Shoya, M., and Sugita, S. (2004). Study on the pozzolanic properties of rice husk ash by hydrochloric acid pre-treatment. Cement and Concrete Research 34:521–526.

Kartini, K. (2011). Rice husk ash–pozzolanic materials for sustainability. International Journal of Applied Science and Technology. 169 pp.

Megat, M. A., Brooks, J. J., Shahid, K. and Patrice R. (2011). Influence of supplementary cementitious materials on engineering properties of high strength concrete", Construction and Building Materials 15:2639-2648.

Nick, Z. E. (2009). Rice husk ash, normal concrete *Expert systems with applications*. California Polytechnic State University 7:323-335.

Siddique, R. (2008). Waste Materials and By-Products in Concrete. Series Engineering Materials India: Springer-Verlag. 414 pp.

Sima, J. (1974). Portland-pozzolona cement: need for a better application" Indian Concrete Journal 48:33-34.

Yogenda, M. R. and Jagadish, K. S. (1988). Pozzolanic properties of rice husk ash, burnt clay and red mud. Journal of Building and Environment 23:303–308.