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Flexural Strengths of Concretes Containing Rice Husk Ash from Different Calcination Methods

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Abstract

This work investigated the flexural strengths of concretes containing rice husk ash (RHA) from different calcination methods. RHA was produced using three different calcination methods namely, Open Air Calcination (OAC), Furnace Calcination (FC), and Stove Calcination (SC). Ordinary Portland Cement (OPC) was partially replaced with RHA from each of the three calcination methods at 5%, 10%, and 15%. Nine concrete beams of 150mm x 150mm x 600mm were produced for each of the three percentage replacement levels of OPC with RHA and for each of the three calcination methods. Nine control concrete beams using 100% OPC were also produced with same dimensions. A mix ratio of 1: 2: 4 (blended cement: sand: local stone) and a constant water/cement ratio of 0.6 were used for the concrete. All the concrete beams were cured by immersion. Three concrete beams from each of the three RHA calcination methods and for each of the three percentage replacement levels of OPC with RHA, as well as three control concrete beams were crushed to obtain their flexural strengths at 28, 90 and 150 days. Multiple regression analysis was used to develop empirical models for predicting the flexural strengths of OPC-RHA concrete for each of the three calcination methods. The results show that the flexural strength values of the OPC-RHA blended cement for all the three calcination methods and at all three percentage replacement levels of OPC with RHA were lower than the control value at 28 days, but increased to become comparable to the control values at some later days. The control flexural strength value rose to 6.18N/mm^2 at 90 days and 6.41N/mm^2 at 150 days whereas the greatest 90 and 150-day flexural strength values for the OPC-RHA concrete were 5.48N/mm^2 and 6.74N/mm^2 respectively. Flexural strength values for FC were highest, followed by values for SC, while values for OAC were lowest. Based on flexural strength values, OPC-RHA blended cement concrete with RHA obtained from FC could be used for all building and civil engineering works at 5-10% OPC replacement with RHA, where early loading of the structural members are not required. The developed models could be used to predict the flexural strength values of OPC-RHA binary blended cement concretes.

Keywords: Blended cement, concrete, pozzolan, rice husk ash, flexural strength, calcination method, open air calcination, stove calcination, furnace calcination.

I. Introduction

Ordinary Portland Cement (OPC) is by far the most expensive component of the materials used in concrete making for housing and civil engineering projects in Nigeria. Therefore, the need to research into more ways of utilizing solid wastes as mineral admixtures to partially replace OPC has continued to increase. Agricultural bye products such as rice husk and saw dust have attracted the attention of many researchers in this regard. Besides reducing the overall cost of concrete works, such mineral admixtures could preserve the non-renewable resources that are required for the production of cement and could, therefore, contribute to sustainable concrete construction.

Several researchers have investigated the use of rice husk ash (RHA) as a pozzolanic material which can be used in partial replacement of cement. Malhotra and Mehta (2004) state that ground RHA with finer particle size than OPC improves concrete properties, including that higher substitution amounts results in lower water absorption values and the addition of RHA causes an increment in the compressive strength. Sakr (2006) and Sata et al. (2007) variously demonstrated that RHA could be a suitable partial replacement for OPC in concrete and mortar to increase flexural and compressive strength, as well as increase durability and resistance to chemical attacks.

Taku et al. (2016) investigated the effect of the calcination temperature on the silica content of rice husk ash by burning in a programmable furnace at temperatures of 400°C, 500°C, 600°C, 700°C and 800°C respectively and at a constant calcination time. The results showed that the silica content of RHA from rice husk calcined at temperatures of 400, 500, 600, 700 and 800°C, respectively varies slightly with calcination temperature but in each case is more than the 70% minimum stipulated by ASTM-Specifications- C618 for pozzolanas. The authors affirm that a comparison of a typical pozzolanic reaction (CH + S + aq→ C-S-H) and Portland cement hydration (C_3S + aq→ C-S-H + CH) shows that it is the silica component of the RHA that contributes to strength development when used as a pozzolan. Varying the calcination temperature of rice husk as well as the calcination time will to a large extent determine whether the silica content of the husk will remain amorphous or produce silica in the crystalline phase (Chandressekhar, 2005; Chandressekhar et al., 2006). The silica content of RHA also depends on the location from which the rice husk is obtained as well as the variety of rice used (Bandara, 1994).

Abalaka (2012) also studied the effects of methods of rice husk incineration on rice husk ash blended concrete and found that the incineration method affected concrete strength. Nehdi et al. (2003) found that at 12.5% replacement, RHA concrete with RHA produced using a Torbed reactor operated at 750^0 had higher compressive strength at 28 days than RHA concrete with RHA produced using fluidized bed technology. They further state that amorphous silica with high reactivity is produced under controlled combustion conditions and that silica in RHA can remain in amorphous form at combustion temperatures of up to 900^0C if the combustion time is less than one hour, whereas crystalline silica is produced at 1000^0C with combustion time greater than 5minutes. Nurdeen et al. (2011) found that calcination temperature of palm oil waste had an influence on the characteristics and pozzolanic activity of palm oil waste ash. Fadzil et al. (2008) studied the properties of ternary blended cementitious (TBC) systems containing OPC, ground Malaysian RHA, and fly ash (FA). They found that at long-term period, the compressive strength of TBC concrete was comparable to the control mixes even at OPC replacement of up to 40% with the pozzolanic material.

Saraswathy and Ha-won (2007) studied the corrosion performance of rice husk ash blended concrete and concluded that RHA as a pozzolan in concrete increases the strength of concrete against cracking. Elinwa et al. (2005) found that saw dust ash can be used in combination with metakaolin as a ternary blend with 3% added to act as an admixture in concrete. Elinwa and Abdukadir (2011) have also investigated the suitability of saw dust ash as a pozzolanic material and found that it could be used in binary combination with OPC to improve the properties of cement composites. Ru-shan et al. (2015) found that the morphology of the resultant silica from calcination of agricultural by-product pozzolans is a function of the temperature and degree of control of the combustion process. They explain that in muffle furnace 600^{0}C is the appropriate temperature for rice husk ash preparation with large specific surface area due to the existence of nanoscale and amorphous silica.

Ghassan and Hilmi (2010) investigated the properties of rice husk ash (RHA) produced by using a ferro-cement furnace, and discovered that incorporation of RHA in concrete increased water demand. They also stated that RHA concrete gave excellent improvement in strength for 10% replacement. Altwair, et al. (2011) found that calcination temperature influences the characteristic activities and pozzolanic activity of Palm Oil Waste Ash. Similarly, Kamal et al. (2008) found that the burning temperature and percentage inclusion of microwave incinerated RHA influenced the strength of concrete. Ettu, Ajoku et al. (2013), Ettu, Onyeyili et al. (2013), and Ettu, Nwachukwu et al. (2013) have also confirmed that partial replacement of OPC with some percentage of RHA improves the strength properties of cement composites, including concrete, sandcrete, and soilcrete.

Since the use of OPC-RHA blended cement concrete is becoming more and more acceptable, there arises a need to produce RHA using calcination processes easily adaptable to dwellers in rice growing communities in South Eastern Nigeria. Hence, this work investigated the flexural strengths of concretes containing RHA obtained from three simple calcination methods that could be easily replicated by local community dwellers.

II. Methodology

Rice husk was obtained from rice milling factories in Afikpo, Ebonyi State in South Eastern Nigeria. This material was air-dried and calcined into ashes using three different simple methods namely: Open air calcination (OAC), Stove calcination (SC), and Furnace calcination (FC). The open air combustion was done in an open chamber at an uncontrolled degree of temperature ranging between 450^{o}C and 600^{o}C. The stove combustion was done using improvised cylindrical stove commonly used by local dwellers at a temperature generally below 700^{o}C. The furnace burning was done using local pit crucible furnace fired with coke at a temperature of 600-800^{o}C. Temperature was measured with a Type-K thermocouple in all the three calcination methods. The rice husk ash (RHA) was sieved and large particles retained on the 600µm sieve were discarded while those passing the sieve were used for this work. No grinding or any special additional treatment was applied to improve the quality of the ash and enhance its pozzolanicity because the researchers wanted to utilize simple processes that could be easily replicated by local community dwellers.

The RHA obtained from OAC had bulk density, specific gravity, and fineness modulus of 780kg/m^3, 1.86, and 1.48 respectively. Corresponding values for that obtained from SC were 760kg/m^3, 1.79, and 1.44 respectively, while values for that obtained from FC were 785kg/m^3, 1.82, and 1.50 respectively. Other materials used for this work are Ordinary Portland Cement (OPC) with a bulk density of 1660kg/m^3 and specific gravity of 3.06; river sand free from debris and organic materials with a bulk density of 1710kg/m^3, specific gravity of 2.64, and fineness modulus of 3.35; crushed local stone of 20mm nominal size free from impurities with a bulk density of 1490kg/m^3, specific gravity of 2.76 and fineness modulus of 5.34; and water free from organic impurities.

A simple form of pozzolanicity test was carried out for the rice husk ashes. It consists of mixing 20g of the ash with 100ml volume of Calcium hydroxide solution [$Ca(OH)_2$] in a 50ml burette, and titrating samples of the mixture against 0.1M H_2SO_4 solution at time intervals of 30mins, 60mins, 90mins, and 120mins respectively using Methyl orange as indicator at normal temperature. The mixture was stirred using a Labnet Orbit shaker (model 1000). The titre value (volume of acid required to neutralize the constant volume of calcium hydroxide-ash mixture) was found to reduce with time, confirming the ash as a pozzolan that fixed more and more of the calcium hydroxide, thereby reducing the alkalinity of the mixture. The chemical analysis of the ashes from the three calcination methods performed using X-ray Fluorescence spectrometer (XRF) showed they satisfied the ASTM C1456 (2013) requirement that the sum of SiO_2, Al_2O_3, and Fe_2O_3 should be not less than 70% for pozzolans.

A mix ratio of 1: 2: 4 (blended cement: sand: local stone) was used for the concrete. Batching was by weight and a constant water/cement ratio of 0.6 was used. Mixing was done manually on a smooth concrete pavement. The RHA was thoroughly blended with OPC at the required proportion and the homogenous blend was then mixed with the fine aggregate and coarse aggregate, also at the required proportions. Water was then added gradually and the entire concrete heap was mixed thoroughly to ensure homogeneity. OPC was partially replaced with RHA from each of the three calcination methods at 5%, 10%, and 15%. Nine concrete beams of 150mm x 150mm x 600mm were produced for each of the three percentage replacement levels of OPC with RHA and for each of the three calcination methods, making a total of eighty-one concrete beams with OPC-RHA binary blended cement for the three different calcination methods. Nine control concrete beams, with same dimension of 150mm x 150mm x 600mm, using 100% OPC or 0% replacement with RHA were also produced. This gives a grand total of 90 concrete beams. All the concrete beams were cured in water by immersion. Three concrete beams from each of the three RHA calcination methods and for each of the three percentage replacement levels of OPC with RHA, as well as three control concrete beams were tested for saturated surface dry bulk density and crushed using the four-point flexural test to obtain their flexural strengths at 28, 90 and 150 days of curing.

Multiple regression analysis was used to develop empirical models for predicting the flexural strengths of OPC-RHA concrete for each of the three calcination methods. Relationships between the variables were established and the model was done in the standard linear-interactive manner according to Cindy and Robert (2007). A statistical adequacy test for the mathematical model was done using statistical Student's t-test at 95% accuracy level. The actual or laboratory flexural strengths and the predicted flexural strengths were used for the test. The following two hypotheses were tested:

i. Null Hypothesis: There is no significant difference between the flexural strengths of laboratory concrete beams and predicted flexural strengths from the model at 95% accuracy level.
ii. Alternative Hypothesis: There is significant difference between the flexural strengths of laboratory concrete beams and predicted flexural strengths from the model at 95% accuracy level.

III. Results and Discussion

The flexural strength values are shown in Table 1 for the control concrete and the OPC-RHA binary blended cement concrete, for each of the three calcination methods (Open Air Calcination—OAC, Stove Calcination—SC, and Furnace Calcination—FC), the three % replacement levels (5%, 10%, and 15%), as well as each of the three days of curing (28, 90, and 150 days). The results show that the flexural strengths generally decreased with increased amount of RHA and increased with the curing age.

It can be seen from Table 1 that the flexural strength values of the OPC-RHA blended cement for all the three calcination methods and at all three percentage replacement levels of OPC with RHA were lower than the control value at 28 days, but increased to become comparable to the control values at some later days of curing. Whereas the control value at 28 days of curing was 5.89N/mm^2, the greatest values of 4.57N/mm^2 (OAC), 3.56N/mm^2 (FC) and 3.04N/mm^2 (FC) were obtained at 5%, 10% and 15% RHA replacement. The control flexural strength value rose to 6.18N/mm^2 at 90 days and 6.41N/mm^2 at 150 days whereas the greatest 90 and 150-day flexural strength values for the OPC-RHA concrete were 5.48N/mm^2 and 6.74N/mm^2.

These results confirm the findings of earlier researchers that concrete containing rice husk ash (RHA) have lower strength than the control concrete at earlier curing ages as a result of the low rate of pozzolanic reaction at those early ages (Hossain, 2003; Adesanya and Raheem, 2009). The silica from the RHA reacts with calcium hydroxide liberated as a by-product during the hydration of OPC to form additional calcium-silicate-hydrate (C-S-H) that increases the binder efficiency and the corresponding strength values at later days of curing.

Table 1. Flexural strengths of OPC-RHA blended cement concrete

% Replacement of OPC with RHA	Calcination Method	Flexural Strength (N/mm^2)		
		28days	90days	150days
0		5.89	6.18	6.41
5	OAC	4.57	4.97	5.35
	SC	2.89	4.42	5.20
	FC	4.07	5.48	6.71
10	OAC	3.04	4.06	4.32
	SC	2.67	4.12	4.51
	FC	3.56	5.03	6.15
15	OAC	2.89	3.11	3.78
	SC	2.57	3.98	4.35
	FC	3.04	4.41	5.32

Thus, the strength gain is both as a result of continued hydration of OPC and the increased pozzolanic reaction (Balendran and Martin-Buades, 2000; Ramasamy, 2012).

Table 1 further shows that the 150 day flexural strengths of OPC-RHA concrete at 5% and 10% replacement of OPC with RHA for Furnace Calcination (FC) method are greater than or comparable to the control concrete strengths. Among the three calcination methods, flexural strength values for Furnace Calcination (FC) are highest, followed by values for Stove Calcination (SC), while values for Open Air Calcination (OAC) are lowest. This could be because the FC method appears better controlled than the others, while the OAC method may not allow for proper and full combustion of the rice husk particles.

The models developed for FC, OAC, and SC methods are shown in Equations 1, 2, and 3 respectively, where Y represents flexural strength, X_1 represents curing age in days, and X_2 represents percentage replacement of OPC with RHA.

$$Y = 4.671559 + 0.0163\ X_1 - 0.1238\ X_2 \qquad (1)$$

$Y = 5.390448 + 0.007114\ X_1 - 0.19713\ X_2$ 2

$Y = 4.325457 + 0.013249\ X_1 - 0.14353\ X_2$ 3

The result of t-test analysis shows that the null hypothesis is accepted and alternative hypothesis rejected. Hence, the models are adequate for predicting the flexural strength values of OPC-RHA binary blended cement concrete at different curing ages and for 5-15% replacement of OPC with RHA, using RHA obtained from any of the three calcination methods investigated in this work.

IV. Conclusions and Recommendations

i. The flexural strength of RHA-OPC Concrete decreases as the percentage replacement of OPC with RHA increases.
ii. The flexural strengths of RHA-OPC Concrete using RHA obtained from Furnace Calcination, Open Air Calcination, and Stove Calcination methods are lower than the control concrete (100% OPC concrete) value at lower ages of hydration, but increase to become comparable to the control concrete values at 150 days.
iii. The flexural strength of RHA-OPC concrete with RHA obtained from Furnace calcination method have higher strength values than those with RHA obtained from Open air calcination and Stove calcination methods. Flexural strength values from Stove calcination RHA are also higher than those from Open Air calcination RHA.
iv. Based on flexural strength values, OPC-RHA blended cement concrete with RHA obtained from Furnace Calcination could be used for all building and civil engineering works at 5-10% OPC replacement with RHA, where early loading of the structural members are not required.
v. Also, based on flexural strength values, OPC-RHA blended cement concrete with RHA obtained from Open Air and Stove Calcination methods could be used for minor building and civil engineering works at 5% OPC replacement with RHA, where early loading of the structural members are not required.
vi. The models developed in this work could be used to predict the flexural strength values of OPC-RHA binary blended cement concrete at 28-150 days of hydration, within 5-15% replacement of OPC with RHA, using RHA obtained from furnace calcination, open air calcination, or stove calcination methods.

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