

The Compressive and Flexural Strengths of Self Compacting Concrete Using Rice Husk Ash

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Abstract

The compressive and flexural strengths of concrete using rice husk ash (RHA) as partial replacement for cement is investigated. The RHA substituted in place of cement were 0, 10, 20, 30, 35 and 100% RHA. The specimens were cured for a period of 7, 14, 21, 28 and 35- day respectively and it was observed that the control specimen (0% RHA) experienced defects such as efflorescence but the RHA-ordinary Portland cement (OPC) specimens did not. The 100% RHA specimen were unable to set and this is perhaps due to the absence of the by-products of hydration process such as calcium-silicate-hydrate (C-S-H) gel known as tobermorite and calcium hydroxide, $\text{Ca}(\text{OH})_2$, and the high SiO_2 content compared to the low content of other important compounds such as Al_2O_3 and Fe_2O_3 in the mix. The compressive and flexural strengths of the concrete were found to decrease with increase in RHA contents with the 10% RHA replacement having the optimum value for improved structural performance at 28-day (control: 22.93 N/mm² and 8.73 N/mm², specimen: 22.22 N/mm² and 6.60 N/mm²) for compressive and flexural strengths. It can be concluded that RHA can be used as a partial replacement for cement in concrete, with the 10% RHA giving the optimum compressive and flexural strengths.

Keywords

Compressive, Flexural, Rice Husk Ash, Incineration Temperature, Pozzolanic Reactivity

Received: April 8, 2015 / Accepted: April 25, 2015 / Published online: May 28, 2015

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1. Introduction

There has been an alarming rate of increase in the price of building materials in recent years. This has engineered the government to source materials to supplement the conventional materials. It is in this regard that this work, private sectors and individuals have to go in search with intends to study with a view to partially replace cement in concrete with rice husk ash (RHA) which is locally available. The whole concept of this idea is to ensure that an average working class citizen of this country (Nigeria) will be able to own a house.

Concrete is a composite material which consists essentially of a binding medium within which are embedded particles or fragments of a relative inert filler in Portland cement

concrete, the binder is a mixture of Portland cement, possibly additional cementitious materials such as fly ash and water, the filler may be any of a wide variety of natural or artificial, fine and coarse aggregates, and in some instances, an admixture according to (Power, 1858, Topcu and Uygungole, 2010). Concrete is presently one of the most popular materials used in building construction and other civil engineering works. When reinforced with steel, it has a higher capacity for carrying loads. Concrete being a heterogeneous material, the quality of the constituents and the proportions in which they are mixed, determine its strength and properties.

(Ad, 2005) reported in ECO-CARE: vast majority of the cement used in construction work is the Portland cement. Portland cement is manufactured by mixing naturally occurring carbonate with materials containing calcium

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carbonate with substances containing alumina, silica and iron oxide. (ASTM 618-05, 2005) define pozzolana as 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, they react with calcium hydroxide which is liberated during the hydration of Portland cement at ordinary temperatures to form compounds possessing cementitious properties. They include pumice, tuffa, volcanic ash, diatomaceous earth, calcined clay, shales, and pulverized-fuel ash (PFA) or fly ash. According to ASTM (2005), by-product material admixtures such as fly ash, RHA, and ground granulated blast furnace slag are attracting much attention as materials that not only contribute to improvement of concrete performance (for example, high strength, high durability, and reduction of heat of hydration) but are also indispensable to the reduction of energy and carbon-dioxide generated in the production of cement (Okamura and Ouchi, 2003).

Ikpong (1993) reported that rice husk is the outer covering of the rice grain consisting of two interlockings. It is usually produced as an agro-waste while processing rice through a process known as threshing. The colour is dependent on the carbon content of the ash.

RHA is a finely fragmented or divided particle of agro-waste product measuring less than (about 1/9 mm) in diameter, it is obtained from the removal of rice grain from its shell called husk, as reported by (Neville and Brooks, 1987). Several institutions have investigated the properties of RHA and found out that it contains higher properties of silica and there has been some commercial exploitation of its pozzolanic reaction with lime. RHA is also described as a fine pozzolanic material, which in itself is poorly cementitious in nature but can form a cementitious compound in the presence of lime and water. The pozzolanic value of RHA depends on the burning conditions. According to Okpala (1987), controlled incineration of the husk to about 700^oc yields amorphous RHA which is highly pozzolanic.

There is an increasing importance to preserve the environment in the present day world. RHA from the parboiling plants is posing a serious environmental threat and ways are being thought of to dispose them. This material is actually a super-pozzolane since it is rich in silica and has about 63 to 90% silica content. A good way of utilizing this material is to use it for making "high performance concrete" which means high workability and long-term durability of the concrete.

1.1. Research Significance

The desire to produce building materials that are affordable to all is the focus of this investigation. Cement is the most

expensive component in concrete production and this has made it inaffordable only to the well to do. The concept is to produce structural concrete with almost equal properties as a standard concrete by partially replacing the cement component with an agro-waste (rice husk). The disposal of this agro-waste is a major problem globally and nationally. It is envisaged that at the end of this investigation two major outcomes are expected viz-vise:

- (i) Production of structural concrete using the rice husk ash with properties comparable to standard concrete.

Success of (i) will invariably lead to proper waste management of the agro-waste (rice husk).

1.2. Properties of Standard OPC and Partially Replaced Raw Rice Husk Ash (RRHA)

Atan and Awang (2011) have reported the following properties for OPC and partially replaced cement with RRHA concrete:

Table 1. Properties of OPC and RRHA Concrete.

(i) OPC

Age (Day)	Density, Kg/m ³	Compressive Strength, Mpa	Flexural, Strength, Mpa
7	2270	36.5	4.5
14	2302	37.6	4.7
28	2290	37.8	5.7
60	2285	45.4	5.8
90	2287	44.7	5.7

(ii) RRHA

Age (Day)	Density, Kg/m ³	Compressive Strength, Mpa	Flexural, Strength, Mpa
7	2253	22.7	3.2
14	2269	29.6	3.5
28	2268	39.8	4.0
60	2268	41.9	6.1
90	2279	42.4	6.2

It is seen from the table, that the RRHA developed early moderate strength of 22.7 Mpa in compression and 3.2 Mpa in flexure. Strength development increases at high rates from 7 days to 28 days in compression and from 7 days to 60 days in flexure. The main functions of the mineral additive (RRHA) in this case is to regulate the cement content so as to reduce the heat of hydration (European Project Group, 2005).

2. Materials and Methods

2.1. Materials

For the determination of the performance of concrete in terms of its engineering properties such as compressive and flexural strengths, the following materials were employed: these include; Ordinary Portland Cement (OPC), Rice Husk

Ash (RHA), Aggregates (fine and coarse), water and consumable (engine oil), and concrete.

The chemical analysis of the OPC-RHA used in this study is given in Table 2. Figure 1, shows the stages of the rice husk ash preparation used in this study-(a) raw rice husk after threshing, (b) the rice husk after grinding and (c) incinerated rice husk forming the ash.

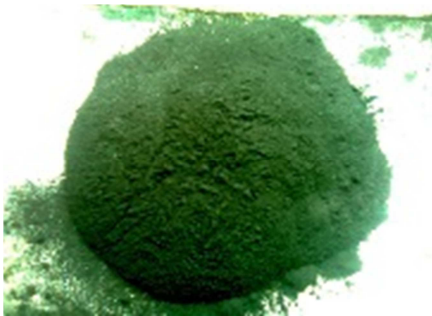
Table 2. Chemical analysis of RHA and OPC used in this study.

Composition(%)	OPC	RHA
SiO ₂	28.03	63.45
Al ₂ O ₃	4.88	2.12
Fe ₂ O ₃	3.98	2.18
CaO	64.67	1.21
MgO	2.34	1.35
SiO ₃	2.75	0.12
Na ₂ O	0.17	1.59
K ₂ O	0.58	0.96
PbO	0.07	-
TiO ₂	0.35	-
LOI (1000 ^o c)	-	5.25

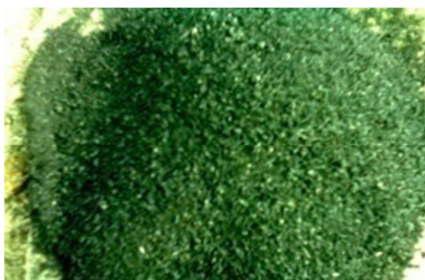
LOI=Lost on Ignition.



(a) Rice Husk.



(b) Ground Rice Husk.



(c) Incinerated Rice Husk Ash.

Fig. 1. Stages of preparation of the rice husk ash.

2.2. Material Preparation

The aggregates used in this study were air-dried for about a week in order to remove any trace of moisture that would have altered the water content of the concrete mixes.

The RHA was ashed by a direct furnace at incineration temperature at a range of 650^oc – 700^oc and after which it was ground into a finely divided powder. A type 1 ASTM C-150 OPC cement was purchased, clean tap water was also made available, including engine oil which served as consumable. Metal moulds were used for the casting of the compressive and flexural specimens. The oil was used to tub the internal surface of all the moulds for easy de-moulding of the concretes.

2.3. Water– Cement Ratio

The water – cement ratio is the ratio of the weight of water (w) to the weight of cement (c) used in the concrete mix and it has an important influence on the quality of concrete produced.

A lower water-cement ratio leads to higher strength and durability but may make the mix more difficult to place. Placement difficulties can be resolved by plasticizers but in this study, plasticizers were not used. Often, the water-cement ratio is characterized as the water to cement plus pozzolanes which influence the strength gain of the concrete.

The water (w) – cement (c) ratio used in this study is given as:

$$\frac{w}{c} = 0.05, \tag{1}$$

and the chosen ratio is in the order of 1:2:4,

where

cement + pozzolan = 1

sand (fine aggregate) = 2

b = breadth of the concrete cube (m)

h = height of the concrete cube (m)

Also in order to obtain the masses required for beams, the volume was calculated to be 0.0135m³ by applying equation 2. Therefore, the mass of a cube of concrete is given as:

$$M. = \rho v \tag{2}$$

where,

ρ = density of a concrete cube (2400kg/m³)

v = volume of a concrete cube (3.375 x 10³m³)

m = mass of concrete cube (kg)

Tables 3 and 4 give the mixed proportion for both compressive and flexural specimen.

Table 3. Mixed proportion of concrete paste for compressive strength test.

OPC (%)	RHA (%)	Water (kg)	OPC (kg)	RHA (kg)	Sand (kg)	Gravel (kg)
100	0	5.40	10.80	0.00	21.60	43.20
90	10	5.40	9.72	1.08	21.60	43.20
80	20	5.40	8.64	2.16	21.60	43.20
70	30	5.40	7.56	3.24	21.60	43.20
65	35	5.40	7.02	3.78	21.60	43.20
0	100	5.40	0.00	10.80	21.60	43.20

OPC = ordinary Portland Cement, RHA = Rice Husk Ash.

Table 4. Mixed proportion of concrete paste for flexural test.

OPC (%)	RHA (%)	Water (kg)	OPC (kg)	RHA (kg)	Sand (kg)	Gravel (kg)
100	0	21.60	43.20	0.00	86.40	172.80
90	10	21.60	38.88	4.32	86.40	172.80
80	20	21.60	34.56	8.64	86.40	172.80
70	30	21.60	30.24	12.96	86.40	172.80
65	35	21.60	28.08	15.12	86.40	172.80
0	100	21.60	0.00	43.20	86.40	172.80

2.4. Calculation Of Compressive and Flexural Strengths

The compressive and flexural strengths of the concrete obtained in this study were calculated using equations (3) and (4) respectively and the results are given in Table 5 and 6

$$\sigma_c = \frac{F}{A} \quad (3)$$

Where,

σ_c = compressive strength of concrete (N/mm²).

F = failure load (N)

A = cross-sectional area of test specimen (mm²)

$$\sigma_b = \frac{3Pa}{bd^2} \quad (4)$$

Where,

σ_b = flexural strength (N/mm²)

P = failure load (N)

a = distance between the loading pins (mm)

b = width of the specimen (mm)

d = breadth or depth of specimen (mm)

Table 5. Compressive strength of concrete with different percentages of RHA replacement and their standard deviation (S.D.).

% Repl.	Compressive Strength (N/mm ²) and Standard Deviation				
	7 day	14 day	21 day	28 day	38 day
0 (CTL)	20.31	21.33	22.67	22.93	23.47
10%RHA	18.44	18.89	21.56	22.22	23.02
20%RHA	15.42	15.64	15.86	16.67	17.16
30%RHA	9.60	12.44	14.04	16.00	16.80
35%RHA	3.19	4.62	6.04	6.49	7.82
S.D.	6.74	6.50	6.68	6.59	6.33

3. Results

The results of the compressive and flexural strengths are given in Tables 5 and 6 respectively.

Table 6. Flexural strength of concrete with different percentage of RHA replacement and their standard deviation (S.D.).

% repl.	Flexural strength (N/mm ²) and standard deviation				
	7 day	14 day	21 day	28 day	35 day
0(CTL)	6.40	7.80	7.90	8.73	9.63
10%RHA	4.00	5.75	5.80	6.60	6.93
20%RHA	3.40	4.87	5.40	6.13	6.47
30%RHA	1.40	1.93	2.13	1.87	2.47
35%RHA	0.73	1.00	1.13	1.87	2.47
S.D.	2.25	2.79	2.79	2.73	2.80

4. Discussions

4.1. Compressive Strength

The results of the compressive strength for the various percentage replacement of RHA concrete and their corresponding averages and standard deviations are given in Table 5 and displayed in Fig.2, showing the effect of percentage RHA replacement and curing ages on the compressive strengths. It could be seen (Fig. 2) that as the percentage of RHA increases, the compressive strength on the other hand decreases in a steady manner. This decrease in the strength is due to the reduction of the cementations properties of the concrete paste. The hydration process of cement produces calcium-silicate hydrate (C-S-H) gel, which is also known as tobermorite and calcium hydroxide, Ca(OH)₂ and of these by products: tobermorite act as a binder in the concrete matrix, but with increase in percentage RHA replacement, the effectiveness of this by-products is

reduced. The effect of curing can also be seen in Fig. 2. Here, it is seen that the strength increases steadily with a corresponding increase in curing age: this is because the more concrete ages, the stronger it becomes. The curing ages in this study were 7,14,21,28, and 35 days respectively. This behaviour in the strength validates the fact that the concrete gain more strength as the hydration process increases with age(Ovri,2000).The control (CTL) specimen at 28-day of curing gave a compressive strength of 22.93 N/mm² which is in the range of compressive strength for structural concrete while the 10%RHA replacement concrete has a compressive strength of 22.22 N/mm², that is about 97% of the mean compressive strength of the control(CTL). From Table 5 also, it could be seen that the 10% RHA replacement gave a more consistent compressive strengths as the CTL and therefore, it could be inferred that the optimum replacement value of RHA for concrete should not exceed 10%RHA.The 20%RHA,30%RHA and 35%RHA strengths were far less than those of the 10%RHA replacement. This is partly due to the higher quantity of the RHA in the concrete mix,that is the less the by-products of hydration which would have acted as binder and because of this, the more porous the material becomes and weaker. According to the American Concrete Institute (ACI and NIST,2010) the compressive strengths of concrete in this study falls within the range 2 N/mm² to 42 N/mm² and therefore, can be classified as medium and structural light weight concretes.

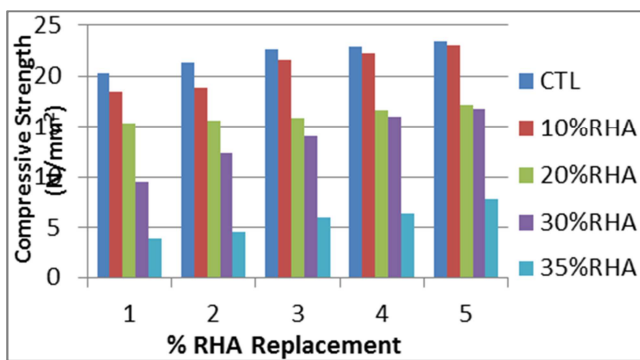


Fig. 2. Compressive strength against %RHA replacement.

4.2. Flexural Strength

For the flexural strength, the same percentage RHA replacement were also used, i.e. 0% RHA (CTL), 10% RHA,20%RHA, 30%RHA and 35%RHA respectively. The results obtained are given in Table 6 and displayed in Figure 3, the effects of percentage RHA replacement and curing ages and the strengths are also given. From the Figure, it is evident that a steady decrease in the strength occurred with an increase in the %RHA contents. This effect can also be attributed to the lower contents of the cementitious products in the concrete matrix. With regards to curing ages as seen in

Fig.3, the strength. increases steadily with prolonged curing, it therefore means that, the more concrete ages, the more the hydration process thereby producing more cementations by-products which leads to the enhancement of the strength of the concrete in question. Concrete usually have low flexural and tensile strengths that is why they are being reinforced with steel bars to improve on their flexural and tensile strengths. The flexural strength of the CTL specimen at 28-day of curing is 8.73 N/mm² while that of the 10%RHA is 6.66N/mm² which is about 76% of the mean flexural strength of the control. Therefore, the optimum percentage RHA replacement recommended for the concrete in this study is 10%RHA.

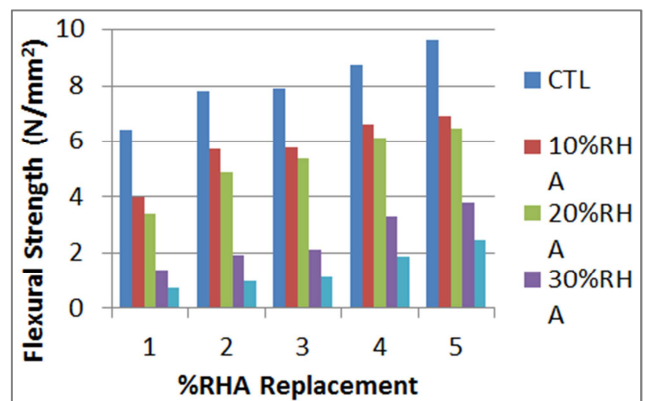


Fig. 3. Flexural strength against %RHA replacement.

4.3. 100% RHA Specimen

Figure 4, shows the specimens made with 100% RHA replacement i.e rice husk ash alone(the absence of cement).It is evident that RHA cannot be used alone in concrete making. RHA itself is a pozzolane which do not possess any cementing properties. From Fig. 4, it was observed that the specimen refused to set even after 24 hours of placement and consolidation, and after de-moulding the particles of the mix refused to set and hardened. This behaviour is as a result of the absence of the by-product of hydration i.e. tobermorite and calcium hydroxide which would have acted as binder.



(a) 100% RHA specimen after de-moulding.



(b) 100% RHA specimen after testing for setting time.

Fig. 4. 100% RHA concrete specimen without setting.

5. Conclusions

Based on this study, the following conclusions could be made:

Structural concrete with a compressive strength of 22.22N/mm^2 has been produced using 10%RHA partial replacement of cement. Beyond this value the compressive strengths fall outside the required range for structural concretes. Optimum flexural strengths were also obtained with the 10%RHA partial replacement.

It has been shown that the compressive and the flexural strengths of the concrete increases with age.

It could be concluded that inexpensive concrete could be produced using RHA as partial replacement for cement which is the most expensive component for concrete.

It was observed that the 100% RHA specimen did not set and with this fact, the use of RHA alone in concrete production is not feasible.

The agro-waste(rice husk) can be properly managed when it is used as a partial replacement in the production of concrete.

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