Relationship between Compressive Strength and Pulse Velocity of medium Grade Concrete incorporating Rice Husk Ash

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Abstract

The partial replacement of cement with rice husk ash (RHA) in concrete has been reported to enhance the properties of the concrete especially its strength. The rice husk was sourced from a local rice mill in Akwa Ibom, Nigeria and fired at temperature range of 650 to 700^{o}c and the ash obtained had high silica content. Four concrete grades of 15, 20, 25 and 30N/mm^2 with cement content replaced by RHA at 0, 30, 40 and 50% and tested at 7, 14 and 28 days were investigated. The compressive strength were determined using both destructive (compression testing machine) and Non-destructive (pulse velocity tester) methods. The results indicated that the compressive strength of concrete incorporating RHA can attain the same order of strength as conventional concrete; and that compressive strength can be predicted from the pulse velocity value since there is a strong linear relationship between the two.

Keywords: *compressive strength, ordinary Portland cement, ground rice husk ash, ultrasonic pulse velocity*

1. Introduction

One material that has the potential not only to augment the supply of cementitious material but which is locally available and economical to produce is rice husk ash (RHA). The burning of the husk can be done either in open heaps, furnaces or in a purpose-made incinerator. The burning operation produces large quantity of ash, about one fifth by volume of husk [1].

In Akwa Ibom and Cross Rivers States of Nigeria, rice is being produce in large quantity and the volume of husk being generated posed an environmental problem. The husk is usually burnt away as a mean of disposal; this is evidence in large heaps of rice husk being burnt along Calabar – Ikom expressway and some other major roads especially in the rice producing communities of the states.

Many works have been carried out on the use of RHA as a pozzolanic material in concrete [2, 3, 4, 5]. One peculiar characteristic that have been discovered from the RHA is the fact that their chemical and physical composition varies depending on the source, geographical location, testing and processing methods. These variations in their compositions also affect the properties of concrete differently. Therefore, this study examined the effect of RHA from Itu-Mbonuso rice mill in Akwa Ibom State, Nigeria.

2. literature review

The utilization of rice husk ash as mineral admixture in concrete provides several advantages. Its incorporation as supplementary cementitious material has led to increase in compressive strength of concrete [6]. According to Sugita *et al*. [7], blending of 20% by weight of RHA with ordinary Portland cement increases the compressive strength of concrete at 28 days by more than 25%. This is attributed to the reduction in effective water cement ratio in concrete blended with RHA as the free water is being absorbed by the added RHA and kept in its mesopores. It has also been reported that the incorporation of RHA as a partial replacement of cement in concrete improved the concrete resistance to sulphate and acid attack [8, 9]. This is because the RHA pozzolanic reaction with calcium hydroxide leaves less lime to react with the sulphate or acid, thus reducing the risk of the expansive calcium sulphoaluminate formation, which can be destructive. It has been observed [6] that the more the RHA replacement, the less the amount of Ca (OH)$_2$ in concrete, and which they attributed to one of the main reasons for the strength enhancement of concrete.

The common method for testing compressive strength of concrete has been the crushing of the concrete cubes or cylinders in a compression testing machine. This method is aptly classified as destructive since it entails irreversible damage to the concrete specimen. A number of non-destructive methods have been worked upon over years and one that has gained wide acceptability for the assessment of strength of concrete is the ultrasonic pulse velocity test.

The measure of pulse velocity in concrete depends upon some of the following factors: water/cement ratio; aggregate/cement ratio; cement type and the amount of voids presence in the solid matter. Kaplan [10] found out that in concrete of the same age, the effects of aggregate/cement ratio and water/cement ratio balance one another so that at a given age, and at a constant workability level there is a unique relation between pulse velocity and strength of concrete.

Cement type affects the pulse velocity for the fact that different types of cement are made by varying their chemical composition and/or their fineness. Silica with lime form the essential cementing compounds – tricalcium silicate (C_3S) and dicalcium silicate (C_2S) in the composition of Portland cement; and rice husk ash contain a high proportion of silica, but a low percentage of lime. In RHA concrete therefore, we are dealing with concrete containing cement which chemical composition is much different from that of the ordinary Portland cement (OPC).

The presence of voids in concrete, as stated by Neville [11] is the most important factor that influences the velocity of ultrasonic pulse transmission. The liberation of calcium hydroxide produced during the hydration of the C_3S and C_2S compounds of Portland cement that react with the silica in the ash filled these voids thereby resulting in a very strong cementitious compounds [1].

It is therefore, from the above discussion, to be expected that the pulse velocity of RHA concrete will be different from that of conventional concrete (that is, concrete containing OPC only as binder) designed for the same strength. The work covers strength of four concrete grades of 15, 20, 25 and 30N/mm^2 at 28 days and concerned mainly with obtaining empirical data on the compressive strength and pulse velocity of RHA concrete as well as establishing the pattern of relationship between the two parameters.

3. Experimental procedure

3.1. Materials

3.1.1. Aggregates

The aggregates used for the study were crushed granite for coarse aggregate and natural sand for fine aggregate. The sieve analysis conducted on the aggregates indicated a uniformly graded soil (Figure 1). The fine aggregate falls within zone one as specified by BS EN 12620: 2002 + AI [12] which make suitable for use as concreting material, and has specific gravity of 2.61; while the coarse aggregate were of nominal maximum size of 20mm, and has a specific gravity value of 2,69.

3.1.2 Cement

Ordinary Portland cement branded as UNICEM produced to NIS 444-1[13] specification was used. The chemical compositions are presented in Table 1.

3.1.3 Rice husk ash

The rice husk was obtained from one of the rice mills in Itu – Mbonuso, in Ini local government area of Akwa Ibom state, Nigeria. The husk was calcined in a furnace to temperature range of 650^{o}c to 700^{o}c; as soon as this range was attained, it was allowed for one hour for the intensity of the heat flame to reduce. The black husk was removed and heaped in an open space for 5 – 7 hours within which period it turned into ash.

Sieving was conducted on the ash using 300µm sieve, and material retained on the sieve was discarded. Materials finer than 300µm size were ground with the aid of steel mortar and pestle. The sieve analysis of the ground ash before use is as presented in Table 2, while the specific gravity is 2.01. The chemical composition and other properties of the ground RHA is as shown in Table 2.

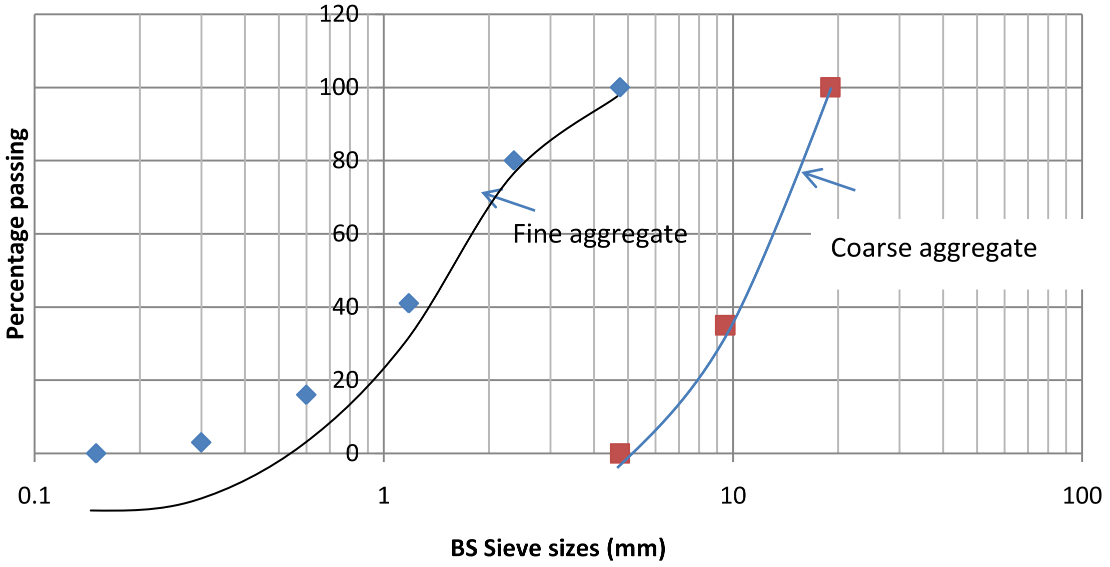

Figure 1. Grading curves for aggregates

Table 1: Chemical Composition of Binders

Chemical composition (%)	Rice husk ash (RHA)	Ordinary Portland cement (OPC)
SiO_2	70.70	20.10
Al_2O_3	12.85	5.25
Fe_2O_3	0.17	3.02
Na_2O	0.13	0.14
K_2O	3.37	0.97
CaO	2.80	62.20
MgO	1.61	1.93
P_2O_5	0.77	0.17
LOI	7.60	1.09

Table 2. Sieve analysis of ground RHA

Sieve size (μm)	Material retained		Percentage passing
	Weight (g)	Percentage (%)	
212	-	-	100
150	12	1.97	98.03
75	202	33.22	66.78
tray	394	64.80	-

3.2. Method

Four types of concrete mixes were used for the study:

(a) Conventional concrete, that is, concrete containing only ordinary Portland cement as binding material;

(b) Concrete containing 30%, 40% and 50% RHA respectively as a partial replacement of cement.

All the four mixes were designed in each case to attain characteristics cube strengths of 15, 20, 25 and 30N/mm^2 respectively at 28 days. The method of mix design adopted is that of the department of Environment. Workability tests (Slump and Compacting factor) were carried out on all the mixes to ensure that low workability range was maintained. The tests were done in accordance with the provision of BS EN 12350-2[14] and BS EN 12350-4[15] for slump and compacting factor respectively.

Immediately after the workability tests, the cubes were cast in 150mm moulds. The moulds were thereafter covered with wet jute bags for 24 hours before de-moulding and subsequently cured in water at a temperature of 29±1^{o}c.

For each of the grade of concrete, three 150mm cubes were cast and tested for each of the three hydration periods of 7, 14 and 28 days. Thus a total of 144 cubes were produced for the study. The combination of cement and RHA was proportioned by volume because of the remarkable difference in the specific gravities of the RHA and the cement. Table 3 shows sample batch quantities of the mixes.

Table 3. Mix proportions (Per M^3 of Concrete)

Design strength (N/mm^2)	RHA content (%)	Cement (Kg)	RHA (Kg)	Water (Litres)	Sand (Kg)	Gravel (Kg)
15	0	220	-	200	980	1060
	30	126	54	210	978	1059
	40	108	72	217	978	1059
	50	90	90	224	978	1059
20	0	270	-	185	873	1112
	30	156	67	197	873	1112
	40	134	89	204	873	1112
	50	111	111	211	873	1112
25	0	298	-	186	842	1115
	30	172	74	204	842	1115
	40	148	98	208	842	1115
	50	123	123	214	842	1115
30	0	321	-	192	812	1122
	30	185	97	196	812	1122
	40	159	106	203	812	1122
	50	132	132	216	812	1122

3.2.1. Ultrasonic Pulse Velocity and Compressive strength tests

The cubes were tested at each of the three curing ages of 7, 14 and 28 days for the ultrasonic pulse velocity. The equipment used for the measurement of the velocity of ultrasonic pulse is that manufactured by the C.N.S. Electronics Company, London, with the trade name PUNDIT.

The PUNDIT (Transit) time was measured for each cube soon after it had been brought out of water, weighed, and the path length measured. Before measurement, the couplant (grease) was applied at the position were the transducers were to be placed and the instrument power lead connected to the main plug while the transducers were connected to the terminals. The transmitting transducer was coupled to one face of the cube and the receiving transducer to the other; the instrument immediately displayed the transit time which was recorded. The path length divided by the transit time gave the pulse velocity for the specimen. This test was usually followed by the compressive strength test for each cube, performed using a universal compression testing machine and as prescribed by BS EN 12390-3[16].

4. RESULTS AND DISCUSSIONS

4.1. Fresh paste

4.1.1. Setting times

The consistency values as shown in Table 4 increases from 29.33% to 53.87% as RHA increases from 0% to 50%. The water required for a standard consistency was noted to increase as the RHA content increases. This can be attributed to the finer particle sizes of OPC/RHA blended cement as much water is required for proper lubrication.

Initial setting times were 1.73hours for plain cement paste and 2.45, 3.40 and 4.68 hours for the paste containing 30%, 40% and 50% RHA content respectively; while the final setting times were 3, 4.50, 5.67 and 6.50 hours for the pastes containing 0%, 30%, 40% and 50% RHA content respectively (Table 4).

These values clearly indicated that there is an increase in both the initial and final setting times of all pastes containing rice husk ash over plain cement paste. This may be attributed to the slower pace of heat – induced evaporation of water from the OPC/RHA pastes due to lower cement content [17]; and because the reaction between cement and water is exothermic, a greater amount of heat would be evolved by the plain cement paste because of its higher cement content. The setting times for the plain and pastes containing RHA all satisfied NIS 447 [18] requirements of 45 minutes minimum initial setting time and maximum 10 hours final setting time.

Table 4. Standard consistency and Setting Times of Pastes

RHA content (%)	Consistency (%)	Initial setting time (Hr. + minutes)	Final setting time (Hr. + minutes)
0	29.33	1 + 44	3 + 00
30	38.99	2 + 27	4 + 30
40	46.56	3 + 24	5 + 34
50	53.87	4 + 41	6 + 30

4.2. Fresh concrete

4.2.1. Slump and compacting factor values

The workability tests performed on the mixes using slump and compacting factor methods presented in Table 5 revealed that to attain the same low workability level in all the mixes containing OPC/RHA with that of the conventional concrete, higher water content was required. This is reflected in the increase in the water/cementitious ratios as the percentage of the RHA increases in all the four design strengths, which have been calculated on the assumption of constant cement content by weight. The results obtained agreed with the earlier results [1, 2].

The higher water contents in mixes containing RHA could be attributed to the proportion of carbon present in the ash and the high fineness of the ash which meant a greater specific surface to be wetted and lubricated.

Table 5. Actual water/Cementitious ratios, Slump and Compacting factor values of mixes

Design strength (N/mm^2)	RHA content (%)	Water/Cementitious ratios	Slump (mm)	Compacting factor
15	0	0.89	16	0.84
	30	0.91	15	0.86
	40	0.94	20	0.87
	50	0.96	14	0.88
20	0	0.65	17	0.85
	30	0.68	14	0.86
	40	0.71	14	0.87
	50	0.74	19	0.89
25	0	0.60	16	0.84
	30	0.63	21	0.88
	40	0.68	20	0.86
	50	0.71	20	0.88
30	0	0.58	14	0.85
	30	0.60	15	0.88
	40	0.62	13	0.86
	50	0.64	12	0.87

4.3. Hardened concrete

4.3.1. Compressive strength

The compressive strengths of all the mixes up to 28 days hydration are shown in Tables 6, 7 and 8 for 7, 14 and 28 days respectively. From Table 6, the compressive strength for 0% and 30% RHA concretes attained over 60% of the designed strengths at the age of 7 days. At 14 days, the strengths of mixes containing 40% and 50% RHA made over 70% of the 28-day designed strength (Table 7). The compressive strength continued to increase with age up to 28 days, all the mixes, except those designed for 25N/mm^2 and 30N/mm^2 and containing 50% RHA, attained their designed strength (Table 8). This indicates that grades 15N/mm^2 to 30N/mm^2 OPC/RHA concrete can attain the same order of strength as conventional concrete at the age of 28 days.

The rate of strength gain of the OPC/RHA mixes increased after the age of 7 days. The strength development of conventional concrete at early all ages is solely a function of cement hydration whereas, the strength development of OPC/RHA concretes at later ages depends on cement hydration as well as pozzolanic reaction involving the silica and alumina present in RHA. It is therefore obvious why the rate of strength gain of the OPC/RHA concretes is higher than that of the conventional concretes beyond 7 days. The compressive strength results agree with those of Ikpong [17].

Table 6: 7-day Compressive strength and Pulse velocity of conventional and OPC/RHA concretes

Design strength (N/mm^2)	RHA content (%)	Density (Kg/m^3)	Pundit Time 10^{-6} (s)	Pulse velocity (Km/s)	Compressive strength (N/mm^2)
15	0	2276	47.4	3.16	13.14
	30	2273	49.2	3.05	12.09
	40	2322	48.7	3.09	8.94
	50	2254	52.6	2.85	5.65
20	0	2353	44.3	3.39	18.56
	30	2304	42.4	3.55	16.70
	40	2266	45.5	3.30	14.11
	50	2342	45.7	3.34	11.14
25	0	2325	41.8	3.59	21.71
	30	2294	43.4	3.47	17.80
	40	2323	44.2	3.40	14.11
	50	2290	43.1	3.49	9.99
30	0	2380	38.0	3.95	26.45
	30	2372	39.7	3.79	21.16
	40	2283	42.9	3.50	15.61
	50	2278	45.6	3.29	8.46

Table 7: 14-day Compressive strength and Pulse velocity of conventional and OPC/RHA concretes

Design strength (N/mm^2)	RHA content (%)	Density (Kg/m^3)	Pundit Time 10^{-6} (s)	Pulse velocity (Km/s)	Compressive strength (N/mm^2)
15	0	2320	38.6	3.89	17.82
	30	2239	43.7	3.43	16.04
	40	2367	48.5	3.09	14.27
	50	2262	45.9	3.27	10.33
20	0	2340	42.8	3.50	22.58
	30	2323	41.8	3.59	17.16
	40	2294	40.3	3.72	14.45
	50	2328	41.6	3.61	11.52
25	0	2335	44.5	3.37	25.52
	30	2337	40.0	3.75	22.46
	40	2306	41.6	3.61	19.65
	50	2345	42.3	3.55	16.59
30	0	2392	34.0	4.41	29.14
	30	2307	37.0	4.05	24.77
	40	2308	38.1	3.94	21.27
	50	2321	40.2	3.73	18.07

Table 8: 28-day Compressive strength and Pulse velocity of conventional and OPC/RHA concretes

Design strength (N/mm^2)	RHA content (%)	Density (Kg/m^3)	Pundit Time 10^{-6} (s)	Pulse velocity (Km/s)	Compressive strength (N/mm^2)
15	0	2349	34.5	4.35	23.66
	30	2293	34.8	4.31	21.29
	40	2291	42.1	4.56	19.87
	50	2294	42.8	3.50	18.93
20	0	2312	30.7	4.89	31.54
	30	2333	37.3	4.02	27.76
	40	2292	36.6	4.10	25.86
	50	2295	38.0	3.95	23.97
25	0	2368	32.1	4.67	33.13
	30	2304	34.9	4.30	29.15
	40	2336	36.2	4.14	26.84
	50	2276	37.3	4.02	24.85
30	0	2373	32.7	4.59	41.16
	30	2289	34.6	4.34	36.22
	40	2309	38.8	3.87	30.05
	50	2324	37.2	4.03	26.75

4.3.2. Ultrasonic pulse velocity

Pulse velocity decreased as the RHA content increased as shown in Tables 6, 7 and 8. The explanation for this is that for the mixes containing RHA, the required water to attain the same workability increased as the RHA content increased. The effect of this would be that more capillaries are left in the RHA concrete as hydration progressed. The presence of voids in concrete has been recognised to be the most important factor that influences the velocity of ultrasonic pulse transmission [11]. The speed of pulse propagation is much less through voids than through solid matter, this increases the time of travel of the pulse in voids and hence decreases the calculated velocity. It is observed that there is an increase in the values of the pulse velocity with age of the concrete. This increase in pulse velocity with age can be related to the fact that calcium silicate and aluminates hydrates produced by the pozzolanic reaction of RHA in concrete serves to fill unoccupied spaces in the concrete. It then follows that less will be the volume of capillary pores and the greater would be the velocity pulse propagated through the concrete.

4.3.3. Compressive strength - Pulse velocity relation

Figure 2 shows the plot of cube compressive strength against pulse velocity for the OPC/RHA concretes at all ages, RHA contents and design strengths. From the graph, the relationship between compressive strength, f_{cu} in (N/mm^2) and pulse velocity, v in (Km/s) is of the form: $f_{cu} = 13.49v - 30.30$. The coefficient of correlation is 0.825 indicating a strong linear relationship between the two parameters. It means that the cube compressive strength can be predicted from the pulse velocity for OPC/RHA blended concrete up to 28 days hydration period.

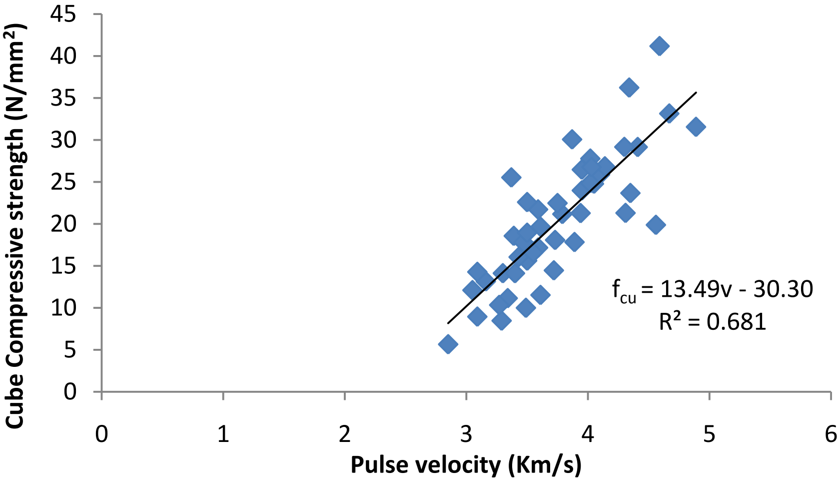

Figure 2: Variation of Cube Compressive strength with Pulse velocity for all ages, design Strength and all replacement levels of OPC with RHA.

5. Conclusions

The following conclusions were drawn from the study:

1) The combined percentages of silica, alumina and iron oxide in the ash used in the study was over 70% and therefore satisfied the ASTMC618 [19] requirements for class F Pozzolans.
2) Higher water content was required for mixes containing RHA to attain the same workability as concrete without RHA.
3) The setting times of both conventional paste and paste containing RHA were within the recommended range for ordinary Portland cement as per NIS 444-1[13].
4) The compressive strength and the pulse velocity of RHA concrete increased with age but decreased with the RHA content. The regression equation for the two parameters is $f_{cu} = 13.49v - 30.30$.
5) The ultrasonic pulse velocity can be used to assess the strength of rice husk ash concrete up to 28 days hydration.

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