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Utilization of Ashes of Some Agricultural Wastes in Concrete: Effect on Strength and Water Absorption Properties

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Abstract

In this study, rice husk ash (RHA) and saw dust ash (SDA) were mixed with Portland limestone cement (PLC) in various proportions to produce concretes having 28-day target strength of 30 MPa. Four mixes were utilized in the study – a plain mix containing only PLC and three ternary blends containing 80% PLC and 20% of RHA and SDA in varying proportions of 15% RHA + 5% SDA, 10% RHA + 10% SDA and 5% RHA + 15% SDA. Concrete cubes were prepared from these mixes and cured for 3, 7, 28, 56 and 90 days. Various tests including consistency, initial and final setting time, compressive strength, and water absorption were conducted. The results showed that the addition of RHA and SDA to PLC resulted in an increase in the consistency, initial and final setting times of the cement paste. This was attributed to the hygroscopic nature of the ashes and their high specific surface area making them to demand more water. The compressive strengths of the ternary blends were seen to be lower than that of the plain mix at all ages. The water absorption test result showed that more water was absorbed by the concrete samples prepared from the mixes containing blends of RHA and SDA, as compared to those prepared from the plain mix. Overall, the ternary blends had inferior performance as compared to the plain mix. It was also observed that the performance of the ternary blends worsened as the RHA content decreased.

1. Introduction

Concrete has been the major component of most civil engineering structures. The major constituent of concrete is Portland cement and it is responsible for the binding of the other components – aggregates and water. Due to the high cost of Portland cement and the emission of greenhouse gases associated with its production [1], many researchers have been in search of alternative materials that can be used to partially or completely replace cement.

The use of supplementary cementitious materials such as fly ash, ground granulated blast furnace slag (GGBS), silica fume and metakaolin, as partial substitutes for Portland cement has been on the rise over the past decades. However, most of these materials are industrial byproducts and are not readily available in most developing countries. This has given rise to the use of ashes of agricultural wastes such as rice husk. Rice husks are the hard protective coverings of rice grains which are separated during the rice milling process. It is an abundantly available waste material in all rice producing countries and contains about 30% - 50% of organic carbon. Rice husk does not possess any pozzolanic property, but when it is burnt to form ash, it becomes pozzolanic and can be used as a supplementary cementitious material [2]. Saw dust is an organic waste produced from the mechanical milling of wood into shapes and sizes. The dust is usually used as a domestic fuel. The ash produced by the burning of saw dust is a form of pozzolana.

Pozzolanic materials, such as rice husk ash (RHA) and saw dust ash (SDA), are commonly used as partial replacements for cement in concrete to enhance its properties. These materials react with calcium hydroxide in the presence of moisture, producing additional cementitious compounds. Several researchers have shown that the use of these materials in concrete can lead to improved strength, reduced permeability, and enhanced resistance to chloride ion penetration [3 – 5].

Fapohunda [4] studied the properties, structural characteristics and application potentials of concrete containing wood waste as partial replacement of one of its constituent materials. The research was on the structural behavior and application potentials of concrete wood waste, in the form of saw dust ash (SDA) as partial replacement of cement, or saw dust as partial replacement of fine aggregates, or as wood aggregates as partial replacement of coarse aggregates. The results obtained showed that (i) with the appropriate mix design, wood waste, either in the form of saw dust ash, or wood aggregate, or wood dust; can be incorporated into the concrete mix to develop structural concrete that satisfies codes requirement, provided the replacement is not 20%; and (ii) concrete incorporating SDA has good durability properties against most of the process of deterioration encountered by concrete in service life. Hence, it was concluded that the use of saw dust waste in concrete will enhance sustainable structural and constructional practices. Similar findings were also reported by Dulipalla [6] in their study on the possibility of using saw dust as a constructional material by partial replacement of cement.

Balwankule [5] conducted an experimental study on the strength characteristics of cement mortar with rice husk ash (RHA) used as partial replacement of ordinary Portland cement (OPC). Cement mortar paste were proportioned with varying weight of RHA as partial replacement of OPC in the range of 0% to 15%, with a gradual increase in the RHA content by 2.5%. It was discovered that the compressive strength increased as the number of days of curing increased for each percentage RHA replacement. Rahman [7] observed that the compressive strength of normal concrete and light weight concrete was almost similar for 7, 14 and 28 days of curing with the inclusion of RHA and glass powder as partial replacement of light weight aggregate in composition. The apparent porosity of the light weight concrete was found to be slightly higher than that of the normal concrete, but the bulk density was about 13% lower than that of the normal concrete.

Ettu [8] investigated the compressive strength of ternary blended cement sandcrete containing rice husk ash (RHA) and sawdust ash (SDA). The results they obtained showed that very high sandcrete strength values could be obtained with OPC-RHA-SDA ternary blended cement. Ukpai [9] also studied the effect of rice husk ash on concrete produced with saw dust ash. They observed that for a given mix, the water requirement increases as the rice husk ash and saw dust ash content increases.

In most of the studies where RHA and SDA were used, they were used in the same proportions to replace Portland cement. Since RHA and SDA have different physical and chemical properties, it will be interesting to see how the properties of the concrete will be impacted when RHA and SDA are used in varying proportions to replace Portland cement. Hence, in this study RHA and SDA were used in varying proportions to partially replace Portland cement to produce ternary blends, and thereafter the performance of these ternary blends were compared to that of Portland cement.

2. Materials and Methods

2.1 Materials

Cement:

The cement utilized in this study was Portland limestone cement (PLC) of grade 42.5. It was obtained from local vendors and conformed to the specifications given in BS EN 197-1:2011 [10]. The physical and chemical properties of the cement are shown in Tables 1 and 2 respectively.

Rice Husk Ash (RHA) and Saw Dust Ash (SDA):

Rice husk was obtained from a rice mill factory located at Uromi, Edo State, while the raw saw dust was obtained from wood factory in Benin City, Edo State. The rice husk and the saw dust were burnt under controlled atmospheric conditions in an oven at a temperature of 800°C, to produce rice husk ash and saw dust ash respectively. The physical and chemical properties of both materials are shown in Tables 1 and 2 respectively.

From Table 2, it can be seen that the silica content is high for both RHA and SDA while that of the cement was low. The specified silicon dioxide content to be used for cement is to be within the limits of 17 – 25% [10], while the higher content is within the limit for the material to be defined as a pozzolan. It can also be observed Table 2 that the sum of the silica content, alumina content and the iron (III) oxide content for both materials is greater than 70% by weight, which implies that both materials are pozzolanic in nature [3].

Table 1: Physical properties of cementitious materials

Property	PLC	RHA	SDA
Specific gravity	3.15	2.06	2.18
Fineness modulus (%)	-	2.96	1.96

Table 2: Chemical properties of cementitious materials

Property	PLC	RHA	SDA
Silicon dioxide (SiO_2), %	21.00	73.60	67.20
Aluminium oxide (Al_2O_3), %	4.13	0.21	4.10
Calcium oxide (CaO), %	62.50	1.30	4.21
Iron oxide (Fe_2O_3), %	3.30	0.35	3.49
Magnessium oxide (MgO), %	1.87	1.43	3.39
Sodium oxide (Na_2O), %	0.37	0.18	1.00
Loss on ignition (LOI), %	1.53	2.89	2.6
$SiO_2 + Al_2O_3 + Fe_2O_3$		74.16	74.79

Aggregates:

Fine and coarse aggregates were used for the study. The fine aggregate used was river sand, and it conformed to the requirements of EN 12620:2002 [11]. The coarse aggregate was crushed granite. It had a maximum particle size of 20 mm. The sieve analysis of the fine aggregate is shown in Table 3, while the physical properties of the aggregates are shown in Table 4.

Table 3: Sieve analysis of fine aggregate

Sieve Size (mm)	Passing (%)
2.36	97.9
2	96.4
1.18	88.6
0.6	65.4
0.425	54
0.3	30.5
0.212	12.1
0.15	5.7
0.075	1.9

Table 4: Physical properties of aggregates

Property	Fine aggregate	Coarse aggregate
Specific gravity	2.64	2.70
Bulk density (kg/m^3)	1540	1618
Water absorption (%)	1.73	1.81

Water:

Casting and curing of the concrete specimens was done with potable water obtained from the University’s main water supply line. The water is clean and free from any visible impurities. It conforms to BS EN 1008:2002 [12] requirements.

2.2 Preparation of Test Specimen

Four (4) concrete mixes were used for this study. The nomenclature of the mixes as well as the proportion of the various materials contained in the mixes is shown in Table 5. The mix designated as CRS00 is the control mix and does not contain any pozzolanic material. The mix designated as CRS1505 contains 80% of Portland limestone cement (PLC), 15% of RHA and 5% of SDA; while the CRS1010 mix contains 80% of PLC and 10% each of RHA and SDA. The fourth mix designated as CRS0515 contains 80% PLC, 5% of RHA and 15% of SDA. The mixes were designed to have 28-day target strength of 30 MPa. The mix design was done following the procedure in COREN Concrete Mix Design Manual [13]. A water-to-cement (w/c) ratio of 0.55 was adopted. The mix design obtained is shown in Table 5. In order to obtain the ternary blends, 20% by weight proportion of the PLC was replaced with RHA and SDA to give the final mix ratios shown in Table 6.

The constituent materials of the various mixes in Table 6 were weighed out separately and placed in the concrete mixer. After mixing, the wet concrete was checked for consistency by performing the slump test to verify that the slump used is in accordance with the concrete mix design. Thereafter, the concrete was placed into 100 mm cube moulds. The moulds were covered with thin polythene sheets and left to cure under air in the laboratory for at least 24 hours, after which the cubes were demoulded and taken to the curing room, where they were left to cure until the day of testing.

Table 5: Output of mix design

Cement (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
425	235	609	1131

Table 6: Mixing ratios of the constituent materials

Mix ID	PLC	RHA	SDA	Fine aggregate	Coarse aggregate	Water
CRS00	1.00	0.00	0.00	1.43	2.66	0.55
CRS1505	0.80	0.15	0.05	1.43	2.66	0.55
CRS1010	0.80	0.10	0.10	1.43	2.66	0.55
CRS0515	0.80	0.05	0.15	1.43	2.66	0.55

2.3 Test Methods

Consistency of cement and setting time determination:

For the determination of the consistency of the cement, RHA and SDA paste, the Vicat apparatus was used and the procedures used in the determination was in accordance to specifications given in BS EN 196-3:2016 [14]. Also, the same apparatus is used for the determination of the setting time of the cement paste and the procedure used were as those for the consistency tests.

Compressive strength:

Compressive strength was determined on triplicate samples at specific ages of 3, 7, 28, 56 and 90 days, in accordance with BS EN 12390-3:2019 [15]. At the test age, the concrete cubes were brought out from the curing room, surface dried, and weighed before testing. The compressive strength (in MPa) was taken as the average failure load (in kN) divided by the cross sectional area of the concrete cube (in mm^2), as shown in Equation 1 below:

$$P = \frac{F}{A} \tag{1}$$

where:

P Compressive strength in MPa
F Failure load in kN
A Cross sectional area of concrete cube in mm^2

Water absorption test:

Water absorption test was carried out in accordance with BS1881-122:2011 [16], on triplicate concrete cubes. After 28 days of curing, the concrete samples were placed in an oven and dried at a temperature of 105°C for 24 hours. Thereafter, the samples were immersed in water for 30 mins. The mass of the samples were recorded before and after immersion in the water, and the water absorbed (W_a) as a percentage was obtained using the expression below:

$$W_a = \frac{M_f - M_o}{M_o} \times 100 \tag{2}$$

where:

M_0 dry weight of the sample, in grams
M_f weight of the sample after immersing in water for 30 mins, in grams

W_a water absorbed in %

3. Results and Discussions

3.1 Results of Consistency Tests

The results of the consistency tests that were conducted on paste samples are shown in Table 7. From the table, it can be seen that the mixes containing the pozzolanic materials i.e. RHA and SDA, had higher consistency and setting times. Similar findings were also reported by [9, 17, 18]. The increase in the consistency and setting times of the paste samples containing RHA and SDA can be attributed to the hygroscopic nature of the ashes and their high specific surface area making them to demand more water [19]. For the mixes containing the pozzolanic materials, the consistency and setting times were seen to increase with increase in the SDA content and decrease in the RHA content. The reason for this can be attributed to the lower fineness modulus of SDA as seen in Table 1.

Table 7: Results of consistency test

Mix ID	Consistency (%)	Initial setting time (mins)	Final setting time (mins)
CRS00	28.5	63	315
CRS1505	32.8	95	328
CRS1010	35.7	113	338
CRS0515	36.4	147	387

3.2 Compressive Strength

Figure 1 shows the compressive strength of the concrete produced from all the mixes. From the figure, it was observed that as the age increased, the compressive strength of all the mixes increased. Also, the compressive strength of the mixes containing the pozzolanic materials (RHA and SDA) was seen to be lower than that of the control mix i.e. CRS00. This agrees with previous studies by [9, 20, 21].

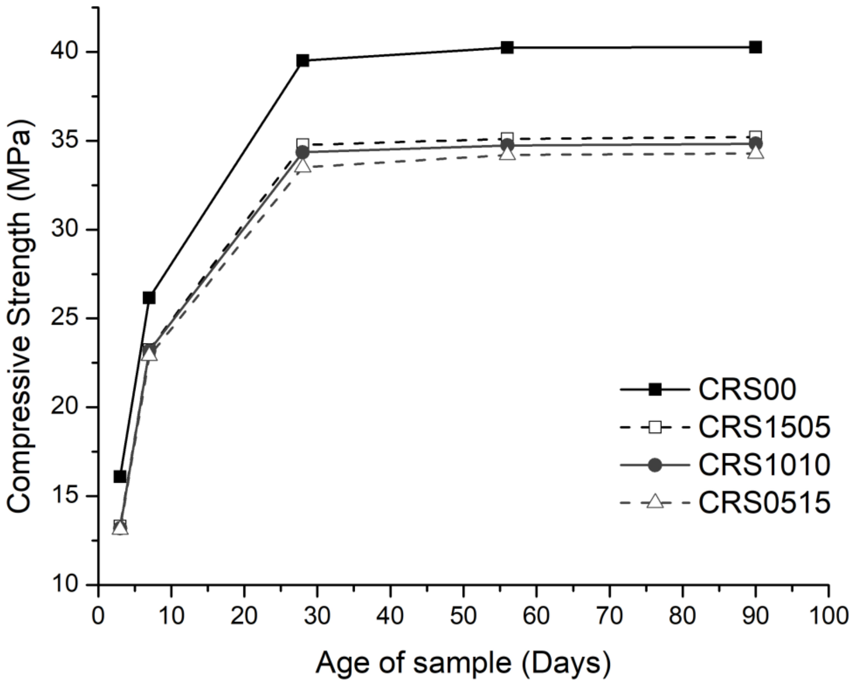

Figure 1: Compressive strength development for all the mixes

For the mixes containing the pozzolanic materials, as the RHA content decreased, the strength was also seen to decrease for all the ages tested. This implies that the presence of the RHA improved the compressive strength more than SDA, for the concretes produced from the mixes containing the pozzolanic materials. Similar observation was also made by [8] in their study on the strength of ternary blended cement sandcrete containing Afikpo rice husk ash and saw dust ash, where they recommended that a disproportionate blending of RHA and SDA should be in favour of RHA for optimization of the strength of the ternary blended mixes.

At 28 days, although the strength of the pozzolanic mixes were lower than that of the control mix, they were still greater than the target strength of 30 MPa. This implies that both pozzolans can be effectively incorporated into concrete mixes.

3.3 Water Absorption

The results obtained from the water absorption test conducted on 28-day old samples are shown in Table 8.

Table 8: Water absorption for all the mixes at 28 days

Mix ID	Water absorbed (%)
CRS00	6.03
CRS1505	7.01
CRS1010	8.73
CRS0515	7.92

The percentage of water absorbed by the concrete samples is an indication of their porosity. A low percentage of water absorption suggests a more compact and denser concrete, which is generally associated with better strength properties. From Table 8, it can be seen that the percentage of water absorbed by the ternary blends were higher than that of the plain mix. This indicates that the concrete samples of the plain mix had a lower porosity than the concrete samples of the ternary blends, and therefore explains their higher strength seen in Figure 1. Kewalramani [22] showed that concrete that is extremely good have their water absorption to be between 4 to 5%, very good concrete might be between 5 to 6%, while commercial concrete might be between 6 to 7%, but ordinary concrete have its value to be between 7 to 10%. Based on this, it can be seen the concrete samples prepared from the first two mixes in Table 7 i.e. CRS00 and CRS1505 mixes, fall under the category of commercial concrete, while the remaining two mixes fall under the category of ordinary concrete.

4.0 CONCLUSIONS

Based on the results of this study, the following conclusions are drawn:

1. Higher consistency and setting times were recorded for the mixes containing RHA and SDA, and this was attributed to the hygroscopic nature of the ashes and their high specific surface area making them to demand more water.

2. The compressive strength of the mixes containing the pozzolanic materials (RHA and SDA) was seen to be lower than that of the control mix. For the pozzolanic mixes, as the RHA content decreased, the strength was also seen to decrease for all the ages tested. This implies that the presence of the RHA improved the compressive strength more than SDA.

3. The percentage of water absorbed by the ternary blends was higher than that of the plain mix. This indicates that the concrete samples of the plain mix had a lower porosity than the concrete samples of the ternary blends.

Overall, the outcome of this study shows that the use of RHA and SDA blends are good for the production of ordinary concrete. They are not advisable to be used for the production of commercial concrete, where the qualities are to be very good or extremely good.

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