ISSN 2229-5518

Mechanical and Durability Properties of Rice Husk Ash Blended Concrete

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Abstract— Due to the high level of carbon emission associated with the use of limestone cement based concrete in the construction industry, the development of concrete utilizing supplementary cementitious materials (SCMs) has been considered as alternative sources of binders in the production of concrete. These SCMs include industrial and agricultural wastes such as rich husk. SCMs are materials that have high silica content which enables them to polymerize and serve as binder. Rice husk ash, a common agricultural waste, is in abundance in the Nigeria. Hence, in this current study, the effects of rice husk ash on self-compacting concrete were examined through experimental processes in the laboratory by the partial replacement of cement with rice husk ash in designed concrete matrices. Rice husk obtained from rice mills were incinerated and blended into powder form and introduced into self-compacting concrete mix as partial substitute of cement in percentages of 0, 5, 10, 15 and 20. Tests implemented on the prepared concrete samples include the workability tests (which were implemented in accordance to EFNARC guidelines on self-compacting concrete), mechanical performance tests (compressive strength and splitting tensile strength tests) and durability performance tests (compressive strength and mass losses on exposure to acid attack). The workability of the prepared self-compacting concrete was improved by the inclusion of rice husk ash. The compressive strength and mass of concrete samples exposed to acid attack in 56 and 90 days showed that the reduction in compressive strength masses of concrete containing 5% and 10% rice husk ash were less than those of the corresponding control samples whereas, at 15% and 20%, the reductions were more than the control. Hence, with up to 10% replacement of cement with rice husk ash, the durability performance of rich husk ash blended concrete was better compared to the control samples. The compressive strength and splitting tensile strength results showed that the inclusion of rice husk ash into the concrete matrix reduced the mechanical performance of the concrete. However, as the water-binder ratios increased and at later curing age (28 days), the reduction in compressive strength and splitting tensile strength were minimized. Compressive strength more than 75% of the control samples were obtained.

Index Terms— Rice husk ash, compressive strength, Splitting tensile strength, workability, durability, self-compacting concrete, acid resistance, strength deterioration factor, mass deterioration factor.

1 Introduction

For several years, limestone cement has been the sole binding material implemented in cementitious materials. Although, in recent time, other supplementary cementitious materials have been used. It has been observed that limestone concrete poses environmental challenge due to its high carbon content. It emits high carbon to the environment thereby, increasing the amount of carbon based compounds the environment is exposed to. Consequently, development of concrete with supplementary cementitious materials with less carbon content have been integrated into the design of concrete mix. Examples of such materials include rice husk ash, silica fume, metakaolin, wood ash, ground-granulated blast-furnace slag etc [1], [2].

Nagrale et al [3] noted that about 120 million tonnes of rice husk are produced globally from which an estimated 24 million tonnes of rice husk ash that can serve as pozzolanic material can be obtained. Nigeria records huge amount of rice husk as a waste product of rice production. Therefore, a huge possibility of obtaining rice husk ash locally [1].

Rice husk ash is produced from the combustion of rice husk under controlled temperature ranging from 10^{o}C per minute to 700^{o}C per minute [4]. It contains about 86% silica as the primary constituent. Other constituent compounds include oxides of aluminum, iron, calcium, magnesium, manganese, sodium, potassium and sulfur [5]. It is easily affordable; therefore, provides an economic advantage as supplementary cementitious material in the production of self-compacting concrete. The production of conventional concrete material is expensive and increases the cost of production. However, rice husk ash incorporation in the design of concrete materials reduces the amount of limestone cement used thereby reducing the cost of production [6].

Various studies have been implemented to evaluate the structural performances of concrete prepared with rice husk ash incorporated as admixture. These studies are implemented using various mixing methodologies and varying nature of results have been obtained for mechanical, workability and durability properties assessed.

Bui et al [7] evaluated the compressive strength of rice husk blended concrete. Rice husk ash was implemented in concrete matrices in partial replacement by weight. Normal Portland cement concrete and gap-graded binder mixtures were the two grades of cement concrete that were evaluated. Results showed that rice husk ash improved the strength for both grades of concrete in early curing ages. However, at later ages, the strength development was lower for the mixture containing rice husk ash.

Ganesan et al [8] studied the compressive and split tensile strengths of concrete blended with rice husk ash to determine the optimum level of replacement of cement with rice husk ash. The replacement of rice husk ash up to 30% showed positive effects on the compressive and splitting tensile strength of concrete as observed from the obtained results.

Rahman et al [9] in their experimental study, investigated the influence of uncontrolled burnt rice husk ash on the mechanical properties of concrete. In the study, rice husk ash was used as partial replacement of cement in percentages of 0, 20, 30 and 40%. The result revealed that that the compressive and splitting tensile strength decreased with increase content of rice husk ash. The researchers noted that the reduction in strength was as a result of excess amount of rice husk ash in the mix which were more than required quantity. There existed leached out extra silica that replaces part of the cementitious material and does not contribute to the strength of the concrete.

Venkatunarayanan & Rangaraju [10] carried out an investigative study to determine the effect of unground rice husk ash (URHA) and ground rice husk ash (GRHA) on the compressive, split tensile and flexural strength and elastic modulus of concrete. In the preparation the concrete mix, the mineral additives were used in partial replacement of cement in 7.5% and 15%. The result of URHA and GRHA were compared to those of the control mix and silica fume blended concrete to determine their mechanical viability. For URHA concrete, the initial compressive strength, split tensile strength, flexural strength and setting time of the concrete improved compared to the control samples. At both levels of replacement of cement, GRHA showed significant improvement in the properties of Portland cement concrete. However, beyond 7.5% replacement of cement by GRHA, compressive strength, elastic modulus, split tensile strength and flexural strength were not significantly improved. However, the results obtained for samples prepared with silica fume were observed to have superior qualities than the RHA blended concretes.

The compressive strength, elastic modulus and split tensile strength of self-compacting concrete were evaluated via an experimental study by Molaei Raisi et al [11]. In the concrete mix, concrete mix at various water-binder ratios were prepared with replacement of cement with rice husk ash at percentages of 5, 10, 15 and 20. Concrete samples were cured for 3, 7, 28, 90, 180 and 270 days. Results obtained showed that the compressive strength, elastic modulus and splitting tensile strength of the concrete increased by increment of rice husk content up to 5%. The inclusion of rice husk ash into the concrete mix beyond 5% resulted in decrease in evaluated properties. The researchers noted that the increment in strength in the early stages of rice husk ash inclusion was due to the reactive rice husk ash particles that react with calcium hydroxide and water to form more C-S-H that results in the formation of denser microstructure of the self-compacting concrete.

Adesina & Olutoge [12] investigated the strength development of concrete blended with rice husk ash and lime. Three sets of concrete mix were studied; control mix (concrete with only cement), concrete blended rice husk ash and concrete with both rice husk ash and lime. Compared to the control samples, blended concrete showed lower compressive strength. However, the compressive strength of rice husk ash-lime blended concrete were observed to be greater than those containing only rice husk ash. As the content of the combined additives increased, the compressive strength increased. The evaluation of strength development in the concrete showed that there was higher early age strength development in the ternary concrete. However, due to lime leaching, this development became impaired in the presence of water. But as age of curing increases, reaction between lime and rice husk ash becomes dominant, thereby overtaking the lime leaching.

Workability of concrete containing rice husk ash have also been evaluated. In the assessment carried out by Naji Givi et al [13] the workability of concrete mix prepared by the partial replacement of cement with two sizes of rice husk ash; 5 microns and 95 microns were observed to have improved. However, higher slump values were observed for concrete containing 95 microns rice husk ash compared to those containing 5 microns.

Rahman et al [9] in their investigative study on the passing ability, filling ability and segregation resistance of concrete blended uncontrolled burnt rice husk ash in partial replacement to cement in 0, 20, 30 and 40%. All workability results were within acceptable range.

The workability of concrete was observed to have decreased on increasing content of rice husk ash in self-compacting concrete as observed from the T_{50}, V-funnel and slump flow test carried out on the fresh concrete samples. It was noted by the researchers that the passing and filling ability of the self-compacting concrete were reduced by rice husk ash [11].

Rice husk ash inclusion into concrete resulted in reduced filling ability of the concrete mix prepared as observed from the study carried out by Ameri et al [14]. Also, in the same study, the addition of bacteria cells did not show any effect on the workability of the concrete.

Furthermore, the durability of rice husk blended concrete have been studied as shown in some of the following studies. The water permeability, chloride diffusion and chloride permeation of concrete blended with rice husk ash were evaluated for concrete samples prepared with partial replacement of cement with rice husk ash up to 30%. The incorporation of rice husk ash resulted in the reduction of water permeability, chloride diffusion and chloride permeation thereby enhancing the durability of the concrete [8].

The porosity, chloride penetration and resistance to acid attack in marine environment of rice husk ash concrete were investigated by Vigneshwari et al [15]. In the study, it was observed that the replacement of silica fume with rice husk ash reduced the chloride penetration and porosity of the concrete under both normal curing and steam curing conditions. The improvement in these properties increased with increase in the replacement level. Also, the performance of the concrete increased with increase in replacement level in acidic and marine environments. However, better performances were observed for steam curing than in the normal curing.

Praveenkumar et al [2] evaluated the durability of concrete blended with rice husk ash and nano TiO_2 through chloride penetration test and hydrochloric acid resistance test. In the chloride penetration test, concrete mixes cured for 14 and 28 days were subjected to rapid chloride penetration test to determine their electrical conductance. From the test conducted, results showed that the concretes blended with rice husk ash and nano TiO_2 showed low chloride penetration while the control mix showed moderate chloride penetration. Also, the deterioration of the concrete was examined under acidic environment. Concrete mixes subjected to acid attack for 14 and 28 days were examined. For the blended concretes, the weight loss for concretes exposed for 28 days were more than the 14 days. Hence, the deterioration in the concretes increased as the duration of exposure increased. However, greater deterioration was observed for the control mix. Therefore, better resistance to acidic attack were observed for blended concretes.

The above studies show that the incorporation of rice husk ash into concrete production improves the workability and durability properties of concrete. However, the strengths of concrete were hugely reduced by the incorporation of rice husk ash. This was observed to be due to factors such as quality of rice husk ash produced, the dosage of rice husk ash used and mix design method. Therefore, this study was implemented to address this by adopting a suitable mix design that will minimize the strength reduction of self-compacting concrete upon the incorporation of rice husk ash.

2 Experimental Programme

2.1 Materials

Ordinary limestone cement obtained from Dangote Cement conforming to NIS 444 was implemented as the primary binder in the concrete prepared. Sharp water sand was used as fine aggregates while granite of average size 20mm was implemented as coarse aggregate. To enhance the flowability of concrete, polycarboxylate ether (PCE) based superplasticizer was used.

The rice husk used in the study was obtained from rice mills in the northern part of Nigeria, incinerated and grounded to ashes before being applied supplementary cementitious material which was used as partial substitute for cement.

All samples were prepared in the Structural Laboratory in the Department of Civil Engineering, Rivers State University.

2.2 Sample Preparation and Mix Design

The self-compacting cement based and rice husk ash blended concrete were prepared in accordance to the DOE mix design methodology. Rice husk ash blended concrete were prepared with 0%, 5%, 10%, 15% and 20% replacement of cement.

The mix proportion for the prepared concrete are summarized in Table 1 below.

Table 1.
Mix Proportion

Mix	Percentage replacement (%)	Cement (kg/m³)	Fine aggregate (kg/m³)	Course aggregate (kg/m³)	Rice Husk Ash (kg/m³)	Water (kg/m³)	Superplasticizer (1.2% of Binder Content)
0.30	0	533.33	674.02	945.68	0	160	6.40
	5	506.67	674.02	945.68	26.66	160	6.40
	10	480	674.02	945.68	53.33	160	6.40
	15	453.34	674.02	945.68	79.99	160	6.40
	20	426.67	674.02	945.68	106.66	160	6.40
0.35	0	457.14	700.73	983.15	0	160	5.49
	5	434.28	700.73	983.15	22.86	160	5.49
	10	411.42	700.73	983.15	45.72	160	5.49
	15	388.57	700.73	983.15	68.57	160	5.49
	20	365.71	700.73	983.15	91.43	160	5.49
0.40	0	400	720.76	1011.26	0	160	4.80
	5	380	720.76	1011.26	20	160	4.80
	10	360	720.76	1011.26	40	160	4.80
	15	340	720.76	1011.26	60	160	4.80
	20	320	720.76	1011.26	80	160	4.80

2.3 Experimental Tests

Tests that were implemented on the fine and coarse aggregates to assess physical parameters such are specific gravity, bulk density and particle size distributions. The results obtained from the specific gravity test show that the specific gravity of fine and coarse aggregates are 2.63 and 2.70 respectively. The bulk densities obtained for fine and coarse aggregates are 1720 kg/m³ and 1611 kg/m³ respectively.

The following tests were implemented on the prepared concrete

2.3.1 Workability Tests

To assess the workability of fresh self-compacting concrete, the procedure outlined in EFNARC standards are followed. The tests implemented and properties assessed are outlined in Table 2 below.

Table 2.
Workability Test and Properties Assessed

S/N	Method	Properties
1	Slump-flow	Filling ability
2	T_{50cm} Slump flow	Filling
3	J-ring	Passing ability
4	V-funnel	Filling
5	V-funnel at $T_{5minutes}$	Segregation resistance
6	L-box	Passing

2.3.2 Compressive Strength Test

Hardened concrete cube samples prepared and cured in the laboratory were subjected to uniaxial compression test after 7, 14 and 28 days of curing.

The samples were subjected to varying crushing loads in the axial plane until failure occured. The failure load is noted. The compressive strength of a material is obtained by dividing the failure load by the cross-sectional area of the material as shown in equation 1 below.

$$\sigma = \frac{P}{A} \quad (1)$$

Where σ is the compressive strength [MPa], P is Failure load [N] and A is the area [mm²].

2.3.3 Tensile Strength Test

Similar to the compressive strength test, the tensile strength test was implemented on the cylindrical samples. However, in this test the load is applied in the lateral direction. Samples cured after 7, 14 and 28 days were tested and the failure loads obtained. The tensile strength was computed using Equation 2 below.

$$F_t = \frac{2P}{\pi DL} \quad (2)$$

Where F_t is the tensile strength [MPa}, P is the failure load [N], D is the diameter of sample [mm] and L is the length of cylindrical sample [mm].

2.3.4 Durability Tests

The durability of the concrete was evaluated through assessment of its resistance to acid attack. Concrete cube samples cured for 28 days were immersed in acid solution containing 2.5%, 5% and 10% concentration of magnesium sulphate. The samples were cured in the solutions for 56 days and 90 days respectively while the solutions were changed after every 14 days intervals.

The compressive strength and masses of samples were measured before and after immersions in the solution to obtain the strength deterioration factors and mass deterioration factors. These are obtained using equation 3 and equation 4 respectively.

$$\mathrm{SDF} = \frac{f_{cu28} - f_{cui}}{f_{cu28}} \times 100 \quad (3)$$

Where SDF = Strength deterioration factor [%], f_{cu28} = compressive strength of sample after 28 days (before immersion in $MgSO_4$ solution) [MPa] and f_{cui} = Compressive strength of samples after immersion in $MgSO_4$ solution in 56 or 90 days [MPa].

$$\mathrm{MDF} = \frac{M_{cu28} - M_{cui}}{M_{cu28}} \times 100 \quad (4)$$

Where MDF = Mass deterioration factor [%], M_{cu28} = Mass of sample after 28 days (before immersion in $MgSO_4$ solution) [kg] and M_{cui} = Mass of samples after immersion in $MgSO_4$ solution in 56 or 90 days [kg].

2.4 Concrete Mix Design

The Department of Environment (DoE) mix design procedure was adopted in this study. This mix design was adopted as it considers parameters such specific gravity in the computation of aggregate proportions. Concrete samples were prepared with only limestone cement as sole binder and used as control samples. Rice husk ash blended concrete were prepared with rice husk ash (RHA) implemented as partial substitute of cement at 5, 10, 15 and 20% respectively for three water-binder ratios of 0.3, 0.35 and 0.4.

The concrete mix design proportion as adopted in the preparation of concrete is shown in Table 3 below.

Table 3.
Mix Proportion

Mix	Percentage replacement (%)	Cement (kg/m³)	Fine aggregate (kg/m³)	Course aggregate (kg/m³)	Rice Husk Ash (kg/m³)	Water (kg/m³)	Superplasticizer (1.2% of Binder Content)

ISSN 2229-5518

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0.35	0	457.14	700.73	983.15	0	160	5.49
	5	434.28	700.73	983.15	22.86	160	5.49
	10	411.42	700.73	983.15	45.72	160	5.49
	15	388.57	700.73	983.15	68.57	160	5.49
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0.40	0	400	720.76	1011.26	0	160	4.80
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	15	340	720.76	1011.26	60	160	4.80
	20	320	720.76	1011.26	80	160	4.80

3 DISCUSSION

The results obtained from the tests carried out in this tests are presented and discussed in this section. The results are presented in tables and figures.

The results of workability tests carried out on fresh concrete samples are presented in Table 4 below. From the results, the slump flow shows that at all water-binder ratios, the slump values increase as the percentage increment of rice husk ash in the mix design increases. Similar trends are observed for J-ring flow and L-box. However, for T_{50} flow, J-ring timing and V-funnel timing, the increase in the amount of rice husk ash reduces the flow timing. In comparison with EFNARC requirement for self-compacting concrete, the results were consistent and shows good workability.

Compressive strength results are summarized in Table 5. The results show the inclusion of RHA into the concrete matrix as partial substitute of cement result in the reduction of compressive strength compared to the control samples. It is observed that the inclusion of RHA reduces the polymerization of the concrete which is faster in the completely limestone based concrete (control). The reduction in strength is more in the early age and reduced as the age of concrete increases as observed from the 7, 14 and 28 days concrete strength.

Similar results are obtained for tensile strength as shown in Table 6. The tensile strength shows decline in values as the percentage inclusion of RHA increases.

Table 4.
Workability Test Results

Mix	**% Replacement of Cement**	**SLUMP FLOW (mm)**	**T50 SLUMP FLOW (SEC)**	**J-RING FLOW (MM)**	**J-RING (SEC)**	**V-FUNNEL (SEC)**	**L-BOX [SEC]**
0.3	0	502	6.3	445	12.1	12.4	0.61
	5	554	5.8	520	11.3	11.3	0.67
	10	592	5.3	575	10.6	10.7	0.73
	15	623	4.9	596	9.5	9.9	0.84
	20	640	4.2	634	8.3	8.5	0.89
0.35	0	525	6.7	449	11.5	11.5	0.63
	5	594	6.1	492	10.8	10.8	0.7
	10	645	4.5	538	10	10	0.79
	15	661	4.1	598	9.3	9.3	0.86
	20	710	3.7	644	8.8	8.6	0.94

0.4	0	575	5.3	467	10.4	11.2	0.67
	5	630	5	524	9.9	10.6	0.72
	10	682	4.4	577	9	9.8	0.8
	15	743	3.9	618	8.1	8.9	0.89
	20	785	3.3	653	7.4	8	0.99

Table 5.
Compressive Strength Result

Mix	**% Replacement of Cement**	**Compressive Strength [MPa]**		
		7 Days	**14 Days**	**28 Days**
0.4	0	40	49.3	50.7
	5	25.8	36.4	37.3
	10	22.7	26.7	36.4
	15	20.4	22.2	30.22
	20	28.4	23.1	27.6
0.35	0	38.2	48	50.7
	5	27.6	39.1	41.3
	10	25.8	32	40
	15	23.6	25.8	36.4
	20	22.2	30.2	33.8
0.3	0	36.4	42.7	49.8
	5	32	40.9	44.4
	10	28.4	35.6	43.6
	15	27.6	33.8	40
	20	26.7	32	37

Table 6.
Tensile Strength Result

Mix	**% Replacement of Cement**	**Splitting Tensile Strength [MPa]**		
		7 Days	**14 Days**	**28 Days**
0.4	0	3.39	4.24	4.53
	5	1.98	1.98	2.83
	10	1.98	1.98	2.26
	15	1.7	1.84	2.12
	20	1.56	1.7	1.98

ISSN 2229-5518

0.35	0	3.11	3.68	4.24
	5	2.26	2.83	2.97
	10	2.26	2.55	3.11
	15	1.84	2.55	2.69
	20	1.84	1.84	2.12
0.3	0	2.83	3.11	3.96
	5	2.55	2.97	3.68
	10	2.83	2.69	3.39
	15	1.98	2.83	3.11
	20	1.98	1.98	2.35

The compressive strength and masses of concrete being measured before and after immersion in the various concentration of magnesium sulphate solutions were used to compute the strength deterioration factor and mass deterioration factors as a measure of resistance against acid attack.

First, the concrete samples with the various mix matrices were weighed and immersed into the acid solutions containing 2.5%, 5% and 10% concentration of magnesium sulphate.

The values of obtained for 2.5% magnesium sulphate solution are shown in Table 7.

From the results shown in Table 7, it is observed that due to acid attack on the concrete, the compressive strength and masses of both control samples and RHA blended concrete reduced. The rate of strength and mass losses are assessed through the strength deterioration factors and mass deterioration factors computed and shown in Table 8. From the table it could be observed that the rate of mass and strength losses reduces as the amount of RHA increases from 0 to 10% inclusion and increases as the amount of RHA increases beyond 10% inclusion. Similar result is obtained for 5% and 10% concentration of magnesium sulphate.

Compared to the control samples, it could be concluded that inclusion of RHA into concrete mix up to 10% substitution rate results in the improvement of the acid resistance of the self-compacting concrete.

Therefore, the durability of self-compacting concrete could be enhanced with inclusion of RHA to about 10% substitution rate with cement under similar mix design condition.

Table 7.
Mass and Compressive Strength of Concrete Samples Before and After Immersion in 2.5% $MgSO_4$ Solution

Mix	% Replacement of Cement	28 Days Strength [MPa]	28 Days Mass [kg]	56 Days Strength [MPa]	56 Days Mass [kg]	90 Days Strength [MPa]	90 Days Mass [kg]
0.4	0	50.7	8.2	49.8	7.8	45.8	7
	5	37.3	8.8	36.7	8.4	34.1	7.6
	10	36.4	8.1	35.9	7.8	33.5	7.1
	15	30.22	8.3	29.7	7.5	27.2	7
	20	27.6	8.7	27	7.4	24.7	7.3
0.35	0	50.7	8.6	49.9	8	47.1	7.3
	5	41.3	8.8	40.7	8.3	38.5	7.4
	10	40	7.8	39.5	7.4	37.9	6.6
	15	36.4	8.3	35.8	7.8	34.1	7
	20	33.8	7.6	33.2	6.5	31.6	6.3

0.3	0	49.8	8.2	49	7.5	46.5	6.7
	5	44.4	8.1	43.9	7.5	41.9	6.7
	10	43.6	7.9	43.2	7.4	41.2	6.6
	15	40	8.4	39.4	7.7	37.7	6.9
	20	37.3	8.6	36.6	7.8	34.9	7

Table 8.
SDF and MDF of Concrete in 2.5% $MgSO_4$ Solution

Mix	% Inclusion of RHA	56 Days SDF [%]	56 Days MDF [%]	90 Days SDF [%]	90 Days MDF [%]
0.4	0	1.78	4.88	9.66	14.63
	5	1.61	4.55	8.58	13.64
	10	1.37	3.70	7.97	12.35
	15	1.72	9.64	9.99	15.66
	20	2.17	14.94	10.51	16.09
0.35	0	1.58	6.98	7.10	15.12
	5	1.45	5.68	6.78	15.91
	10	1.25	5.13	5.25	15.38
	15	1.65	6.02	6.32	15.66
	20	1.78	14.47	6.51	17.11
0.3	0	1.61	8.54	6.63	18.29
	5	1.13	7.41	5.63	17.28
	10	0.92	6.33	5.50	16.46
	15	1.50	8.33	5.75	17.86
	20	1.88	9.30	6.43	18.60

4 CONCLUSION

The fresh, mechanical and durability properties of rice husk ash blended self-compacting concrete have been evaluated in this current study. In the study, the self-compacting concrete was prepared by partial replacement of cement with rice husk ash at percentages of 0, 5, 10 15 and 20% respectively. First, rice husk was obtained from Plateau State (Nigeria), incinerated and blended into fine particles of similar particle size similar to that of cement. In weight percentages, rice husk ash was partially introduced into the concrete mixtures as partial replacement for cement. The rice husk ash blended self-compacting concrete and control samples (ordinary Portland cement concrete) were prepared in the structural laboratory of the Department of Civil Engineering, Rivers State University.

Workability, mechanical and durability tests were carried out on the prepared samples and the following observations were made from the results obtained and the analysis carried out on the results;

1) The tests carried out to assess the workability of the concrete showed consistent result with the requirements of self-compacting concrete. The results from the slump flow test, T_{50} slump flow test, J-ring Flow, V-funnel flow and L-box flow indicated the flowability, passing ability and viscosity of the rice husk ash blended concrete met the requirements of self-compacting concrete as outlined by the EFNARC guidelines for self-compacting concrete.
2) The compressive strength of the concrete showed that as the percentage replacement of cement increased from 0 to 20%, the compressive strength declined

steadily with notable decline at early age for all water-binder ratios. However, as the curing age increased from 7 to 14 and 28 days, the decline rate of compressive strength reduced significantly.

3) The decline in compressive strength of rice husk blended concrete compared to the control sample could be attributed to the poor rate of hydration of rice husk ash compared to Portland cement. This affected the bonding of concrete aggregates.
4) The 28 days compressive strength showed less decline in compressive strength especially for the 0.3 and 0.35 water cement ratios.
5) The tensile strength showed similar performance as the compressive strength of the concrete. As the percentage replacement of cement increased, the tensile strength of the concrete samples reduced slightly across water to cement ratios.
6) The durability assessment result which was carried out through the assessment of acid attack resistance (compressive strength and mass losses) through exposure of concrete samples to acid attack for 56 and 90 days, showed that for RHA-blended concrete containing 5% and 10% RHA exhibited a better durability performance compared to the control samples. The RHA content reacted with the calcium hydroxide formed during the hydration process of cement to form more calcium silicate hydrate gels. This reduces the availability of calcium hydroxide for acid attack (reaction). Hence, maximum of 10% inclusion level of RHA is recommended for use in the design of RHA-blended concrete.

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