



Performance Evaluation of Rice Husk Ash as Partial Replacement of Cement in Concrete in a Marine Environment at Escravos River, Niger Delta Area, Nigeria

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ABSTRACT: Cement has proven to cause environmental problems during its production and to be a relatively high-cost material in concrete production. Environmentally friendly, alternative binders like Rice Husk Ash (RHA) have recently been brought to bear. Therefore, the objective of this paper is to evaluate the performance of RHA (under controlled temperature and burning time) as a partial (10% and 20%) replacement of cement in concrete in a marine environment at Escravos River, Niger Delta Area, Nigeria. Concrete samples prepared with the 10% and 20% RHA in the laboratory were exposed to brackish water samples from the Escravos River, at 3 days, 7 days, 28 days and 90 days and the results compared with that of PLC concrete cast. Data obtained show that the workability of fresh concrete reduced with increase in RHA and further reduced, mixing with salt water. RHA contributed positively to the setting time of the concrete as it increased the initial setting time and reduced final setting time. 10% RHA concrete performed best under all conditions, with about 10% increase in strength. Further increase led to a slight decline in strength. As the amount of RHA increased, the ability of the concrete to resist chloride penetration, increased, with lesser average penetration depth. 10% RHA concrete showed the strongest rebar-concrete bond. 10% RHA is optimum for partial replacement of cement in concrete in marine environment, as it enhances the performance of the concrete.

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Being the most important ingredient of concrete, cement is a versatile and relatively high-cost material. As it is produced in large quantities, it causes environmental problems and depletion of natural resources. This threat has led to the use of alternative binders that are environmentally friendly, like Rice Husk Ash (RHA). 20% of rice produced annually worldwide, is said to be the agricultural residue, Rice husk (Habeeb et al., 2010). In Nigeria, rice has increasingly become important. 8,342,000 tonnes of grains are produced annually with a 20% husk generation which is 1,668,400 tonnes (FAO, 2021). Most of the husks generated are disposed of either by depositing in the open land and for burning, depositing

on the riverbanks which eventually wash away, using for mulching, using for bedding in poultry and pig sheds, etc. Therefore, if these husks are converted to ash, it will greatly improve the environment, economic power and infrastructural capacity of the country. Rice Husk Ash is obtained by burning rice husk in a controlled manner without causing environmental pollution. When properly burnt it has high SiO_2 content and can be used as a concrete admixture. Rice Husk Ash exhibits high pozzolanic characteristics and contribute to high strength and high impermeability of concrete. Endale *et al.*, (2022) researched on the effect of introducing rice husk ash as a partial replacement of cement on the structural properties of concrete. Results

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showed that concrete incorporating RHA had higher compressive strength, splitting tensile strength, flexural strength at various ages and improved durability. Patil *et al.*, (2020) inferred that the incorporation of RHA in concrete results in improved compressive strength and flexural strength. Jongpradist *et al.*, (2018) investigated the efficiency of Rice Husk Ash as cementitious material in High-strength cement-admixed clay. Test results indicate that up to 35% of RHA could be advantageously added up to enhance the strength if the cement content in the mixture is larger than 10. The quality of water used in construction is very important in obtaining certain desired properties of concrete like workability, durability and strength. It is estimated that the earth contains only 2.5% of freshwater most of which is frozen and 97% of seawater (UN-Water, 2006). 8.7% of the total area in Nigeria is covered with salt water and several communities lie around their path of flow. Therefore, large numbers of concrete structures are exposed to sea water either directly or indirectly and needs special attention (Osuji *et al.*, 2020). In many communities surrounded by sea water, it is impossible to produce or cure concrete without sea water. Hussain *et al.*, (2019) investigated the use of salt water in RHA concrete. Specimens were prepared with rice husk ash using fresh water and seawater. The workability of concrete was found to decrease in seawater compared to freshwater mixes, which further decreased with the addition of RHA, although the seawater specimen showed higher strength at 10% replacement of cement with rice husk. RHA has been found to be a suitable supplementary cementitious material and it is relatively available, cheaper and has a renewable source. Hence, it is important to find out how sea water reacts in RHA concrete. The lack of research on economical and environmentally friendly concrete in marine environment has prompted this study. This study will hence contribute towards the collection of the strength properties of RHA concrete in marine environment. Therefore, the objective of this paper is

to evaluate the performance of RHA as a partial replacement of cement in concrete in a marine environment at Escravos River, Niger Delta Area, Nigeria.

MATERIALS AND METHODS

Materials: The materials used for this study consisted of Portland limestone cement, Rice husk ash, fine aggregate, coarse aggregate (maximum nominal size of 20mm), potable water (for fresh water) and brackish water (source: Escravos river)

Concrete Mix Design: A mix of 25N/mm² at 28 days was designed for. Grade M25 was chosen for this work because of the level of exposure of the concrete to harsh environments. Usually, marine concrete is between M20 (for plain concrete) and M30(for reinforced concrete), hence the choice of M25. After considering all necessary parameters, the concrete mix design was done according to code and standards. Hence the mix ratio of 1:1.54:3.78, with w/c ratio 0.5.

Preparation of Concrete Samples: After using a concrete mixer to mix the concrete constituents, concrete cubes of dimension 100mm x 100mm x 100mm were prepared by pouring them full of the concrete into moulds conforming to BS 1881-124:1988 minimum standards, for compression tests and other tests. 135 samples were prepared. Samples for pull out test had a 12mm diameter rebar insert, with a 240mm protrusion. After setting for 24hrs, cube samples for different mix combinations were kept in a water tank (salt water and fresh water as the case may be) to cure for 3 days, 7 days, 28days and 90 days. FF samples were mixed and cured with fresh water, FS samples were mixed with fresh water but cured in salt water, SS samples were mixed and cured with salt water. The humidity (79%) and Temperature (22°C to 30°C) of the Escravos river area was maintained in the curing area.



Fig. 1: Removal of formwork and curing of cubes in salt water

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Workability and Setting Time Tests: To determine the workability, slump test was carried out for fresh concrete made with salt water and RHA in accordance to BS EN 12350-2. Setting time test was done using the Vicat apparatus. In this study, the setting time of PLC mixed with fresh and salt water and RHA+PLC mixed with fresh and salt water was compared according to the procedure stipulated in BS EN 196-3:2005

Compressive Tests On Cubes: To find the strength of the concrete, the procedure in BS 1881-116:1983 was followed. Tests were carried out after 3 days, 7 days, 28 days and 90 days of curing, for each curing condition. The standard error for the compressive strength result was calculated thus:

$$\text{Standard Error} = \sqrt{\frac{\sum(\mu-x)^2}{n}} \quad (1)$$

Where: μ = Compressive Strength of each sample; x = Mean of compressive strength; n = Number of samples

Chloride Ingress/Penetration Resistance Test: The penetration resistance of the concrete to chloride ion was performed using silver nitrate colorimetric method. It uses the principle of which a white deposit is formed through reaction of silver ion (Ag^+) and Chloride ion (Cl^-). AgNO_3 solution was sprayed onto a freshly fractured concrete cross section, which leads to the formation of white and brown zones with a clear colour change boundary. Usually, the depth of the white zone is regarded as the chloride penetration depth, and brown zone corresponds to the chloride free zone. 0.1mol/L silver nitrate solution was used based on the brightness of colour appearing on the concrete surface. A suitable ruler was used to measure the penetration depths from centre to both edges at intervals of 10mm as recommended by NT Build 492 (2000). The test was carried out on only cement concrete cubes, 10%RHA concrete cubes and 20%RHA concrete cubes, made with fresh water and cured in salt water for 28 days.

Rebar Pull Out Test: A simple method was chosen to measure the bond strength of FF and SS samples at 28 days, similarly as in Khalaf et al., (2020). In this test, the 12mm diameter rebar insert was pulled out by applying a tension force with loading rate of 0.5 ± 0.2 KN/s in a UTM. The values of the applied force were measured and recorded up till failure. The bond strength was calculated thus:

$$\text{Bond strength} = \frac{\text{Bond failure load}}{\pi * \text{Bar Diameter} * \text{Length of bar}} \quad (2)$$



Fig. 2: Silver Nitrate & Distilled water



Fig. 3: Silver Nitrate on Split Cubes



Fig. 4: Rebar pulled out from cube



Fig. 5: Pull Out test set up

RESULTS AND DISCUSSION

Rice Husk Ash Analysis: Analysis of the RHA shows the presence of SiO_2 in the amorphous phase which is important in the formation of Calcium Silicate Hydrate (C-S-H) which in turn, contributes to higher strength in the concrete. The Rice Husk Ash was composed of SiO_2 (84.62%), P_2O_5 (5.84%), K_2O (4.32%), CaO (2.15%), Cl (1.15%), Fe_2O_3 (0.67%).

Marine Water Analysis: When tested, the water collected from the Escravos River was slightly saline at 2600ppm and brackish in nature, with chlorine content of 886mg/l and Sulphate content of 1300mg/l. The low salinity can be ascribed to the low tide season, when the water was collected, and the point of collection, which is closer to the fresh water. In all, the water collected is a true representation of what people living in that area use for construction.

Workability/Setting Time: Table 1 shows the slump value for the different concrete blends, mixed with fresh water and salt water.

Table 1: Slump Results

Condition	% of RHA	SLUMP (mm)
Fresh water mix	0	185
	10	160
	20	145
Salt water mix	0	175
	10	155
	20	130

The workability of the fresh concrete reduced with increase in RHA replacement. It further reduced when mixed with salt water. This is the result of the large specific surface area of RHA. Fine RHA subsequently absorbs a significant amount of water on its surface and stores the water in its pores, thus resulting in the decrease of free water and lowered slump value (Fapohunda et al., 2017). This causes an increase in the demand for water as RHA replacement increases. Salt attracts and retains water, therefore when mixed in concrete it attracts more water into the pore structure of the concrete. Though the initial and final setting time increases with salt water generally, the initial setting time increases, while the final setting time is reduced when RHA is introduced. The higher the setting time, the lower the strength of concrete produced. This is because salt water increases the setting time of cement which indicates that the strength of concrete produced is reduced (Mbadike and Elinwa, 2011). The sulphates in the salt water react in the alkaline environment of the concrete paste and create highly expansive crystals called ettringites which affects the setting time of the concrete. RHA contributes positively to the setting time of concrete mixed with salt water, as it reduces the final setting

time, resulting in higher strength. RHA with finer particles exhibits superior setting time behaviour. Research has shown the increase in the initial setting time by raising the RHA level in the cement mixture over those of plain cement paste (Monika and Kiranbala, 2013). Because of its fine particles, RHA contributes positively to the setting time of concrete mixed with salt water, as it reduces the final setting time, resulting in higher strength. By replacing of cement with up to 20%RHA the initial setting time is increased by 31.9% with fresh water and 30.7% with salt water; while the final setting time reduces by 13.9% with fresh water and 7.2% with salt water. This helps the concrete when mixed with salt water, as salt water increases the final setting time of concrete. Table 2 shows the initial and final setting time of only cement paste, 10%RHA and 20%RHA cement paste, mixed with fresh and salt water.

Table 2: Setting Time Result

Setting time (Mins)	0% RHA		10% RHA		20% RHA	
	Fresh	Salt	Fresh	Salt	Fresh	Salt
Initial	47	52	57	63	62	68
Final	215	221	198	217	185	205

Compressive Strength Test: Table 3 below shows the averaged compressive strength with standard error of FF, FS and SS samples respectively; for only cement concrete, 10% RHA concrete and 20% RHA concrete.

Table 3: Average Compressive Strength of FF, FS and SS samples

FF	0% RHA	10% RHA	20% RHA
Strength @3days (N/mm ²)	16±0.43	13.6±0.33	13.44±0.64
Strength @7days (N/mm ²)	21.2±0.29	19.08±1.04	18.87±0.70
Strength @28days (N/mm ²)	29.8±0.65	31.89±0.74	29.2±0.51
Strength @90days (N/mm ²)	30.1±0.88	33.11±1.10	29.9±0.36
FS			
Strength @3days (N/mm ²)	16.64±0.31	14.14±0.17	13.98±0.21
Strength @7days (N/mm ²)	22.68±0.45	20.42±0.60	20.19±0.21
Strength @28days (N/mm ²)	27.71±0.36	29.66±0.40	27.16±0.15
Strength @90days (N/mm ²)	26.79±0.63	30.01±0.66	28.39±0.52
SS			
Strength @3days (N/mm ²)	17.6±0.28	14.3±0.28	15.38±0.56
Strength @7days (N/mm ²)	23.74±0.25	16.8±0.36	21.13±0.21
Strength @28days (N/mm ²)	26.8±0.37	28.38±0.32	25.35±0.37
Strength @90days (N/mm ²)	25±0.43	27.99±0.46	26.7±0.37

For cubes cast and cured in fresh water, 10% RHA concrete showed 10% increase in strength at 90days.

20% RHA concrete met the target strength at 90days. Generally, the RHA concrete has low early strength but gained strength steadily over time. Habeeb et al., (2010) confirms this behavior of the RHA concrete. In his study, he mentioned that the concrete strength increased with RHA for up to 10% which resulted in achieving the maximum value, due to the pozzolanic reaction of the available silica from the RHA and the amount of C-H available from the hydration process and due to the micro-filler effect when fine RHA is used. The decrease in the strength by increasing the RHA replacement level is due to the reduction in the cement amount and as a result of that, the released amount of C-H due to the hydration process is not sufficient to react with all the available silica from the addition of RHA and thus, the silica will act as inert material and will not contribute to the strength development except for the fine RHA where it can be considered as a micro-filler. For cubes cast with fresh water and cured in salt water, while the concrete with 0%RHA dropped in strength after 28 days, the 10%RHA concrete increased in strength. The 20%RHA concrete gained strength slower, though steadily. For cubes cast and cured in salt water, the 0%RHA concrete increased in strength up to 28 days and started dropping. 10%RHA concrete increased in strength up till 28days and dropped slightly thereafter. The 20%RHA concrete increased in weight up to 28days and dropped thereafter, while the strength

increased steadily overtime. Generally, there is a decrease in the strength of concrete produced when salt water is used. The decrease is due to the presence of chlorides and sulphates in the salt water (Mbadike and Elinwa, 2011). The early increase in strength of concrete mixed with salt water is due to chlorides contained in the water that tends to accelerate the setting of cement and to improve the strength, while the rate of strength gain is observed to drop after 28 days due to leaching out of soft hydration product or the sulphates contained in the sea water that retard the setting of cement. In this case, the sulphate content of the salt water is high. Also, at 90 days 10% RHA concrete showed better resistance to sulphate attack, with no significant change in size for FS samples. For SS samples, 20% RHA concrete showed better resistance to sulphate attack, with no significant change in size too. The RHA in the concrete reacts with the calcium hydroxide to bring more hydration products. The consumption of calcium hydroxide will enable lesser reactivity of chemicals from the external environment (Neenu, 2017).

Pull Out Strength Test: The table below shows the result of pull out strength test carried out, after curing only cement samples, 10%RHA samples and 20% RHA samples in fresh water for 28days, and comparing with the samples cured in salt water for 28days.

Table 4: Pull Out Strength Result

@ 28 DAYS	FF			SS		
	0% RHA	10% RHA	20% RHA	0% RHA	10% RHA	20% RHA
	16.3	15.8	11.7	14	14.5	8
Max Bond Strength (N/mm ²)	2.16	2.09	1.55	1.86	1.92	1.06

For FF samples, 0%RHA concrete had better bond, though 10%RHA concrete also had reasonable bond. As the RHA increased, the bond strength reduced. This could be because RHA is not as dense as cement (Bangwar et al., 2018). For SS samples, the 10%RHA concrete showed better bond with about 3.2% increase. The 20%RHA concrete showed a weak bond. The bond strength of 10%RHA concrete may have come from its ability to resist sulphate attack and chloride ingress, because of its low permeability.

Chloride Penetration Resistance Test: The result of Chloride penetration resistance test, carried out on only cement concrete, 10%RHA concrete and 20%RHA concrete cast with fresh water and cured in salt water for 28 days, using Silver Nitrate solution, showed that 0%RHA had an average penetration depth of 42mm, 10% RHA had 35mm and 20% RHA had 33mm. The RHA concrete showed lesser chloride permeability, as the percentage of RHA increased.

This is similar to previous study and the behaviour is due to the increase in the amount of pozzolanic reaction and hydration (Francisco et al., 2019). Generally, introduction of RHA in concrete reduces the permeability. Endale et al., (2022) confirms that the use of RHA improved the durability properties (water absorption, chloride resistance, corrosion resistance and sulphate resistance) of concrete.

Conclusion: RHA concrete performs better than Portland cement concrete in marine environment and can be used to partially replace cement up to 10% to 20%RHA. It improves the strength and shows better resistance to chloride permeability and sulphate attack. In marine environment, 10% RHA reinforced concrete performs better, because of the rebar bond strength. Suitable admixtures or other pozzolanic blends with RHA in adequate dosages can be investigated on, to improve workability and the bond strength, without adversely affecting the strength.

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