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Utilization of Mass I Rice Straw Ash (MRSA) in the Production of Eco-friendly Concrete for Sustainable Construction

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Abstract

Rice straws are the waste produced after the threshing of rice. This research considered the utilization of mass I varieties of rice straw ash to produce eco-friendly concrete. The mass I rice straw (MRS) used was gotten from the rice threshing floor in Odingene village, Akpugo community, Enugu state, Nigeria. The rice straw was calcined by open burning at 535 °C to produce the mass I rice straw ash (MRSA). The materials used were preliminary tested to determine their physical properties. The mass I rice straw ash was subjected to chemical composition and XRD tests. The mass I rice straw ash was used to partially replace OPC at 0, 5, 10, 15, 20, and 30%, respectively. The fresh property test, wet and dry density test, and cube strength test were done for all replacement levels. Using the slump test, the concrete's workability was evaluated. Cube strength was determined on the 7th, 14th, 21st, and 28th day of curing in water. For this research, 72 concrete cubes were cast. From the investigation, the percentage increase in mass I rice straw ash replacement decreased the concrete's workability. The samples' compressive strength varied directly with the curing age and inversely with mass I rice straw ash replacement, though at a different rate, with the CC0,100 gaining the highest strength. The CC5, 95, and CC10, 90, attained 6.1% and 2.2% more strength compared to the design strength at the 28th day of curing, respectively. While the CC15,85; CC20,80; and CC30,70 attained 17.3%, 28.9%, and 67.6% lower strength compared to the design strength at 28th day of curing, The result further revealed that both the wet and dry densities of concrete were significantly affected by a higher replacement percentage of MRSA. This study has revealed that 5–10% mass I variety of rice straw ash (MRSA) can be utilized to replace OPC to produce eco-friendly grade 25 concrete for sustainable construction. The developed models were tested and found to be adequate.

Keywords*:* Mass I rice straw (MRS); Mass I rice straw ash (MRSA); Dry density; Compressive strength; XRD pattern; Predictive models

INTRODUCTION

In modern times, concrete production is a concern because of the rapid growth in population and the sharp decrease in the raw materials involved. It is known that concrete is an excellent material used widely for construction purposes [1]–[3]. Concrete is also the preferred choice of construction material [4] because it fast-tracks the growth of infrastructure due to its strength and ability to be formed in different forms, shapes, and sizes [5]. Some research like [6] defines concrete as a composite material. The dry mix consists of cement, coarse aggregates, and fine aggregates. Cement is a major component in concrete production, and the type widely used is Portland cement [7]. According to [8], the cost of concrete production largely depends on its constituent materials. In [9], the study concluded that one of the main challenges to housing is affordability. Also, [10] reported in their study that most developing countries in the world have seen acute shortages in affordable housing infrastructure due to the high cost of building materials. The study in [11] reported that nearly

60% of the sub-Saharan Africa (SSA) population resides in informal settlements due to the fall in housing infrastructure development. The high cost at which ordinary Portland Cement (OPC) is purchased has led engineers and researchers back to the drawing board to look for alternative cementitious material for OPC in concrete production [12], such that many countries of the world now use blended cements for construction [13]. Studies in [14] and [15] reported that globally, agricultural waste is produced from crop farms annually. These wastes include but are not limited to corn cob, Anacardium occidentale nutshell, groundnut shell, rice husk, and straw, which are used as pozzolanas in concrete production.

Studies by [16]–[21] have confirmed the suitability of corn cob ash, Anacardium occidentale nutshell ash, and groundnut shell ash as pozzolanas in concrete production. Also, research by [22]–[25] have shown the effectiveness of rice husk ash (RHA) as an OPC substitute for making durable concrete.

Rice straws are the waste produced after the threshing of rice. The next operation after harvesting mature paddy is threshing [26]. Grains are separated from panicles without removing the husks by threshing harvested paddy on hard surfaces [27] or by using a combined harvester [28]. The study in [29] reported that an enormous amount of rice straw is generated from rice crops and is unsustainably used as crop residue in the fields by farmers. Annual global rice straw generation stands at 731 million tons, out of which 20.9 million tons are generated by Africa, 667.6 million tons by Asia, and 38.6 million tons by Europe [30]. According to [31], rice straw generated by China and India annually stands at 74.70 and 60.08 million tons, respectively.

In Nigeria, African rice and Asian rice were the varieties cultivated in the past by farmers. [32] reported that in modern times, New Rice for Africa (NERICA), Faro 14, Mass I, II, and III, Canada, Chinyereugo, Awilo, E4314, and E4077 have been introduced as new rice varieties. [32] also observed that the mass I variety of rice cultivated in Nigeria has an average plant height of 144.01 cm, an average leaf area of 63.8 cm2, and an average panicle length of 24.7 cm. A study by [33] revealed that the mass variety of rice is cultivated on a large scale by farmers in Enugu State because of the availability of the seedlings. In Nigeria, rice straw is easily available for rice straw ash production. Several studies [14], [34], and [40] have shown the effectiveness of rice straw ash as a substitute for OPC as pozzolanic material in concrete production.

This research aims at using the straw of a specific rice variety widely cultivated in Enugu State, South Eastern Nigeria, popularly known as mass I, to produce rice straw ash (RSA) to replace ordinary Portland Cement in the making of eco-friendly concrete and potentially lower the cost of housing construction in rural areas where mass I rice straw can be found easily and places where ordinary Portland Cement is very expensive and hard to find. This will in turn help authorities and governments at all levels produce sustainable, low-cost housing units for their citizens. Also, according to [41], ordinary Portland cement production has the highest environmental impact among the different components of concrete. Hence, by using rice straw ash, which is a safer and more sustainable building material, as an alternative to cement, environmental pollution will be reduced. The mass-produced rice straw (MRS) will be obtained from rice farms in the rural area of Odingene village in Enugu State, Nigeria. The mass of rice straw will be calcined into ashes (MRSA), and its physical and chemical properties, including concrete slump, compressive strength, and wet and dry densities, will be tested in accordance with relevant British standards (BS) and American standards for testing materials (ASTM).

MATERIALS AND METHODS

The mass-I rice straw (MRS) used for the research was obtained from the threshing floor of a rice farm in Odingene village in Akpugo, Nkanu West, Enugu, Southeastern Nigeria. The rice straw, which was already dry prior to when it was obtained, was cleaned and free from dirt and other unwanted materials. The rice straw was calcined by open burning at 535 °C for one hour and thirty minutes to produce the mass of rice straw ash (MRSA). No improved burning technology was used in producing the MRSA. The MRSA obtained was not further grinded, but sieving was done to remove unburned particles. The MRSA was stored in a sealed plastic bag until it was used. maximum size of 20 mm Crushed granite obtained from Agbani Aggregate Depot in Enugu, Nigeria, was used as the coarse aggregate. The use of a 20-mm maximum size for the coarse aggregates agrees with [42]. The river sand used was good-quality white sharp sand obtained from a sand depot in Enugu (see figure 1). To ensure that the water-to-cement ratio of the concrete was not affected, all the aggregates were air dried and their saturated surface dried.

Fine aggregate (river sand)

Coarse aggregate (granite)

MRSA

OPC (Bua brand)

Figure 1. Materials used for the research

Preliminary tests of the materials' results are shown in Table 3. It includes physical appearance, water absorption, sieve analysis, relative density, bulk density, gradation coefficient, Cc, and uniformity coefficient. Cu and fineness modulus

The OPC and MRSA were chemically analysed using an X-ray fluorescence analyser (Model QX 1279) to determine the different oxide compositions, and an X-ray diffraction (XRD) test was carried out on MRSA to determine its silica phase. At an angle of 2 degrees from 3-700, a width of 2.5, and a speed of 20 m/min, an X-ray Diffractometer-6000 model was used to scan the MRSA using cuka radiation at 60 kV/80 mA. The tests were conducted at Fugro Nigeria Limited's laboratory.

MRSA was used to replace OPC at various percentages shown in Table 1. The 42.5R grade of Ordinary Portland Cement BUA brand bought from a cement outlet in Enugu State, Nigeria, was used in producing concrete samples. The mixing and curing of the concrete were done with good water. A 1:2.2:4.5 mix ratio with a 0.55 free w/c ratio was used at a characteristic target design strength of 25 N/mm2.

Table 1. Concrete types

S/No	Concrete type
1	CC0,100
2	CC5,95
3	CC10,90
4	CC15,85
5	CC20,80
6	CC30,70

CC0,100 means a concrete cube containing 0% MRSA and 100% OPC (control), CC5,95 means a concrete cube containing 5% MRSA and 95% OPC, CC10,90 means a concrete cube containing 10% MRSA and 90% OPC, CC15,85 means a concrete cube containing 15% MRSA and 85% OPC, CC20,80 means a concrete cube containing 20% MRSA and 80% OPC, and CC30,70 means a concrete cube containing 30% MRSA and 70% OPC.

Mixing Of Concrete

The concrete was batched by weight with respect to the mix ratio. Coarse and fine aggregates were first mixed and spread on the hard, clean floor of the laboratory. The cement and MRSA were then spread uniformly over the mixed sand and the coarse aggregate. The materials were shovelled repeatedly from one end to another and cut with a shovel until the mix appeared uniform. Gradually, water was added so that neither water by itself nor cement could escape. The mixing operation has then been repeated as in the dry state until the mixture appears uniform in colour and consistency.

FRESH CONCRETE TEST

Slump Test

Abram's slump cone apparatus was used to carry out slump tests in accordance with [43]. This test gives a measure of the filling ability of concrete. A slump test was conducted on the CC0,100, which is the control, as well as on the CC5,95, CC10,90, CC15,85, CC20,80, and

CC30,70 concrete. The test was carried out just after mixing was completed. The cone height was measured and recorded, and in three layers, it was filled with fresh concrete with 25 blows each. The vertical cone was removed, allowing the concrete to deform on a flat metal tray. The concrete height was measured. The height difference between the cone and concrete after removal was recorded. See table 4.

Specimen Preparation for Wet Density, Dry Density, and Strength Test

Various procedures, including oiling the inside of the 150mm x 150mm x 150mm moulds with the help of a brush to lubricate the moulds and allow for easy de-moulding, The moulds meet the requirements of [44]. Moulding, de-moulding, and curing were done during the process of preparing the concrete cubes for the strength test. The thoroughly mixed concrete was filled into the cubical moulds in layers of three with a mason's trowel. The first, second, and third layers were given a compaction of 25 blows with the rammer at its own weight and were uniformly spread over the cross section of the mould in accordance with [45]. The levelling and smoothening of each mould top were done (see figure 2). A total of 72 cubes were made for this research. After twenty-four hours, the samples were de-moulded and cured in a tank until tested. The laboratory process also considered the precautions noted in [46] and [47].

Wet Density Test

A test for the wet density of the freshly prepared concrete was carried out with respect to [48]. The test was conducted on the CC0,100 as well as the CC5,95, CC10,90, CC15,85, CC20,80, and CC30,70 concrete samples. First, the weight of the empty mould was determined and recorded. The weight of the concrete-filled mould (see Section 2.4) is also determined and recorded. The weight difference between the filled mould and the empty mould is the mass of the fresh concrete. It is divided by the volume of the cube to give the wet density of the concrete; see figure 2.

Figure 2. Freshly cast concrete cubes and wet density test

Concrete Dry Density Test

In accordance with [49], the dry density of the hardened concrete samples was determined. The test was conducted on CC0,100 as well as on CC5,95, CC10,90, CC15,85, CC20,80, and CC30,70 concrete samples. First, the weight of the dry concrete cube is determined and recorded. This weight was then divided by the cube volume to give the dry density of the hardened concrete.

Concrete Compressive Strength Test

The strength of the concrete was determined using a cube strength testing machine after curing the samples for 7, 14, 21, and 28 days. The testing machine meets the requirements of [50]. Triplicate samples of concrete cubes were used for the test. This was done for each of the days of curing in accordance with [51]. The test was conducted in the civil engineering concrete laboratory at Madonna University, Nigeria. Seventy-two (72) samples were crushed (see table 2).

Table 2. Number of samples crushed.

Sample type	Curing ages	Replicates	Number of samples
CC0,100	7, 14, 21, 28	3	12
CC5,95	7, 14, 21, 28	3	12
CC10,90	7, 14, 21, 28	3	12
CC15,85	7, 14, 21, 28	3	12
CC20,80	7, 14, 21, 28	3	12
CC30,70	7, 14, 21, 28	3	12
	Total		72

Model Development

Regression analysis is one of the methods of generating empirical models to predict the values of a dependent response variable in terms of other independent variables. It investigates functional relationships among variables [52]. According to [22], it is expressed in the mathematical form depicted in equation 1.

$$Y = Q\,(X_1, X_2 \ldots\ldots\ldots X_K) \quad (1)$$

In equation 1, Y stands for the dependent variable, and X and K are independent variables. Researchers normally conduct a statistical adequacy test to ensure laboratory values and predicted values have no significant difference.

Working with MS Excel spreadsheet regression, the empirical correlation for this research was statistically conducted. Empirical models for density and concrete strength estimation were done with respect to the standard linear-iterative manner as stated by [53]. The variables' relationships were established. A statistical t-test at a 95% accuracy level was used to test the empirical models. If t Stat t Critical two-tail or t Stat > t Critical two-tail, reject the null hypothesis, that is, accept the alternative hypothesis; otherwise, accept the null hypothesis. Accepting the null hypotheses implies that there is no significant difference between predicted densities and compressive strengths of concrete and laboratory densities and compressive strengths of concrete at a 95% accuracy level. Rejecting the null hypothesis, which means accepting the alternative hypothesis, implies that there is a significant difference.

RESULTS AND DISCUSSION

Preliminary Test

Depicted in Table 3 are the preliminary test results of the materials used for this research. Figures 3 and 4 also show the grading curves of the aggregates.

Table 3. Materials physical properties

Property type	Fine aggregate	Coarse aggregate	MRSA	OPC
Colour	Light brown	Shades of grey	Dark grey	Grey
Relative density	2.65	2.70	2.21	3.09
Water absorption (%)	0.84	0.63	-	-
Bulk density (Kg/m^3)	1645	1700	-	-
Gradation coefficient, C_c	1.12	1.28	-	-
Uniformity Coefficient, C_u	3.13	1.54	-	-
Fineness modulus	3.22	2.02	-	-

By the prescription of the American Standard for Testing and Materials (ASTM) and British Standard International, the results of Table 3 show that the aggregates meet the requirement for use as aggregates in making concrete.

Figure 3. Grading curve of river sand

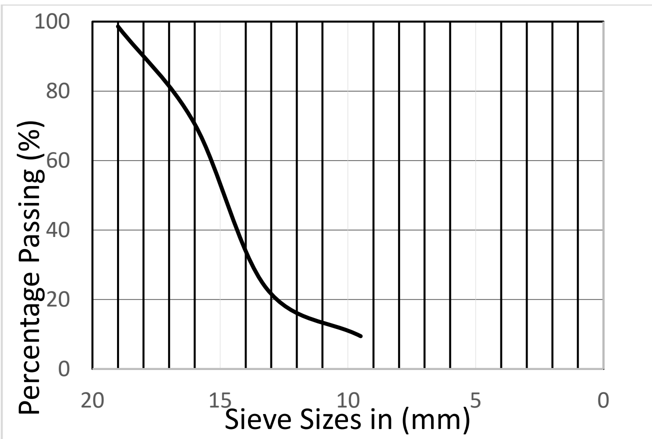

Figure 4. Grading curve of granite

Chemical Composition and X-ray Diffraction of OPC and MRSA

The chemical composition of the OPC and MRSA used for the research is shown in Table 4. According to [54], the combined percentages of (SiO_2 + Al_2O_3 + Fe_2O_3) for any pozzolana suitable for use in making concrete should be more than 70%. The MRSA had 70.49%, indicating that it is a good pozzolanic material, but its loss on ignition of 8.60 is less than 12. The percentage of calcium oxide in MRSA is 3.10%, while it is 65.15% in OPC. Similarly, the percentage of iron III oxide in MRSA is 0.65%, which is very low compared to 2.91% in OPC. Fe2O3 is responsible for imparting colour to cement products, and this could be the reason for the dark gray colour of MRSA. The 68.23% silica composition of MRSA falls within the range reported by [55].

Table 4. Chemical composition of OPC and MRSA

S/No	Oxide	OPC% composition	MRSA% composition
1	Silica dioxide (SiO_2)	20.31	68.23
2	Aluminium oxide (Al_2O_3)	8.04	1.51
3	Calcium oxide (CaO)	65.15	3.10
4	Magnesium oxide (MgO)	3.30	1.72
5	Ferric oxide (Fe_2O_3)	2.91	0.65
6	Manganese oxide (MnO)	0.18	0.13
7	Potassium oxide (K_2O)	0.22	10.40
8	Sodium oxide (Na_2O)	0.72	0.66
9	Sulphur trioxide (SO_3)	2.60	0.79
10	Loss on ignition (LOI)	1.27	8.60

The XRD of the MRSA showed that the ash has traces of crystalline silica in the form of cristobalite and tridymite, indicating that, if the temperature at which the ashes were produced had been increased to between 700 and 1000 °C, more amorphous silica would have crystallized.

Fresh Properties

The result of the slump test is depicted in Table 5. The CC0,100 had a better slump compared to the rest of the concrete types. Slump values decreased as the MRSA percentage increased. The presence of MRSA within the concrete affected its rheological behaviour. Hence, it becomes more unworkable. The slump values for all samples ranged between 20 and 50 mm. The low workability values of the concrete containing high percentages of MRSA can make its casting process in the field a little difficult. The concrete can be made more workable by the addition of chemical admixture in the form of superplasticizers, for example, sulfonated naphthalene formaldehyde condensate, to enhance the casting process in the field.

Table 5. Fresh properties of samples

Sample	Slump (mm)	Degree of workability
CC0,100	30	Low
CC5,95	30	Low
CC10,90	27	Low
CC15,85	25	Low
CC20,80	25	Low
CC30,70	22	Very low

Density of Concrete

Concrete average wet and dry density results are depicted in figures 6 and 7. From figure 6, the wet density generally reduced as the percentage replacement of OPC with mass I rice straw ash (MRSA) increased, except for the 15% replacement, where the wet density was higher than the 10% replacement. This could be attributed to the manual form of compaction used to dislodge air voids during the casting. From figure 7, both the curing age and percentage replacement level affected the dry density of the concrete cubes, though at different rates. The dry density decreased insignificantly at lower percentages of replacement but was significant at the 30% replacement level. This is largely because OPC has a higher relative density compared to MRSA. Also, from figure 7, it could be seen that the dry density at 15% replacement was greater than the 10% replacement level, and the 7th day curing age dry density at 5% was higher than the dry density at 14, 21, and 28th day curing ages at the same percentage replacement. This is because of the manual compaction used during the casting. A further look at the result revealed that the dry density insignificantly affected the concrete compressive strength since at 5% replacement of OPC with MRSA, the dry density value at the 7th day was greater than the dry density values at the 14, 21, and 28th days of curing, respectively, but this was not so for the compressive strength values at the same 5% replacement level (see figure 8).

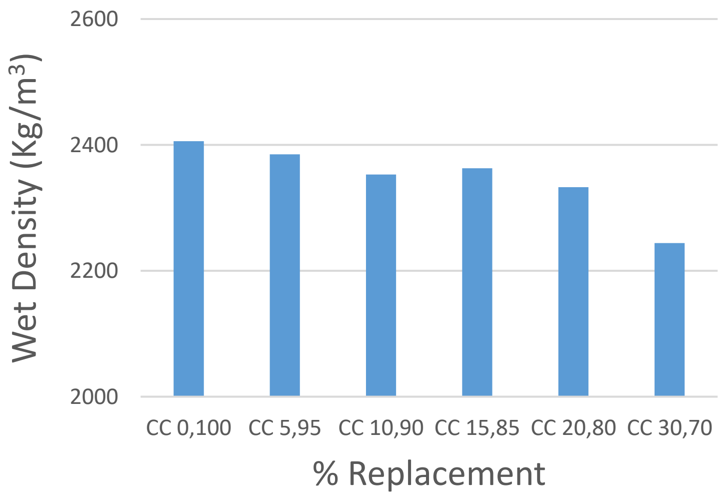

Figure 6. Average wet density of concrete

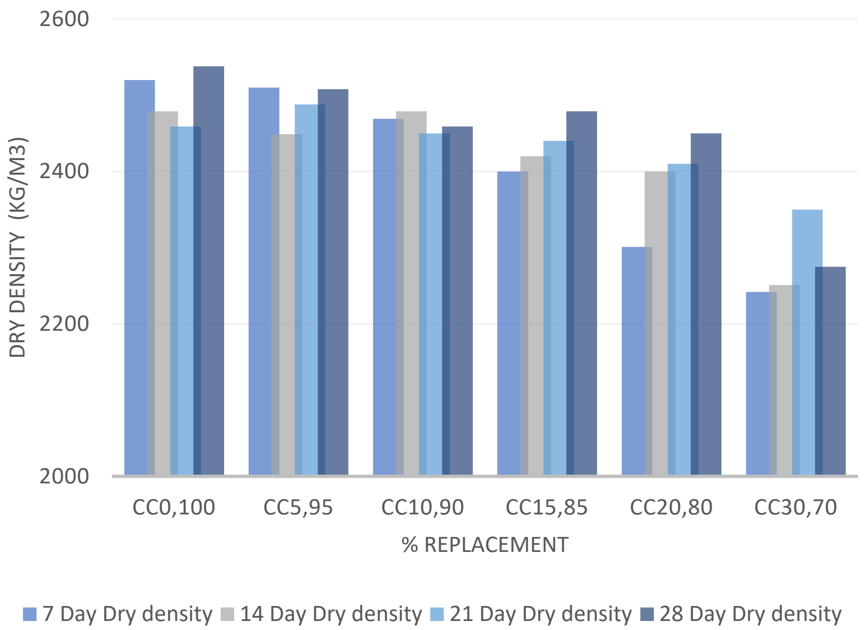

Figure 7. Average dry density of concrete cubes

Strength of Concrete cubes

The results of average concrete cube compressive strength at different levels of replacement are depicted in figure 8. The average cube strength for all the samples increased with time, but at different rates. According to [56], 7th-day cube strength is about 60% of the 28th-day strength. The cube strength ratio of the 7th day to the 28th day of CC0,100, that is, the control sample obtained in this research, was 83%. This high percentage of early strength development by the CC0,100 could be attributed to the brand of OPC used. For the CC5, 95, CC10, 90, CC15, 85, CC20, 80, and CC30, 70, compared to the control, the ratios obtained were 80%, 78%, 59%, 48%, and 20%, respectively. The ratio for 5–10% replacement level is well above 60%, which shows that concrete containing a lower percentage of MRSA has a high early strength development capacity. For the 15–30%, which were less than the 60%, it shows that concrete containing a higher percentage replacement level of MRSA has a low early strength development capacity. The CC0,100 sample maintained the highest compressive strength values over time, while the values for the CC5,95, CC10,90, CC15,85, CC20,80, and CC30,70 samples increased with curing age but were not more than the CC0,100 at the different ages of testing. The increase in strength of all the samples over time implies that as the hydration continues, more calcium silicate hydrate is formed, which increases the concrete's strength. On the 14th, 21st, and 28th days of curing, the CC0,100 sample had a compressive strength of 23.85 N/mm2, 25.36 N/mm2, and 27.26 N/mm2, bringing about a 5%, 12%, and 20% increase, respectively, with respect to the strength gained on the 7th day. Further analysis of the result showed that the CC0,100 concrete gained 9% strength compared to the design concrete strength at the 28th day of curing. The CC5, 95, and CC10, 90 attained 6.1% and 2.2% higher strength than the design strength at the 28th day of curing, respectively. While the CC15,85; CC20,80; and CC30,70 attained 17.3%, 28.9%, and 67.6% lower strength compared to the design strength at the 28th day of curing, this is a drop in the strength of the concrete and could be linked to the percentage increase of MRSA. This might be due to MRSA weighing less than OPC. The lower strength attained by CC15,85, CC20,80, and CC30,70 at the 28th day of curing could also be attributed to the MRSA not being grounded to increase its pozzolanic reactivity.

However, the CC5, 95, and CC10, 90, which are concrete containing 5% and 10% OPC replacement with MRSA, gained compressive strengths of 26.52 N/mm2 and 25.56 N/mm2 at the 28th day of curing, which are higher than the 25 N/mm2 design concrete strength, making it an excellent choice for developing eco-friendly structurally reinforced grade 25 concrete.

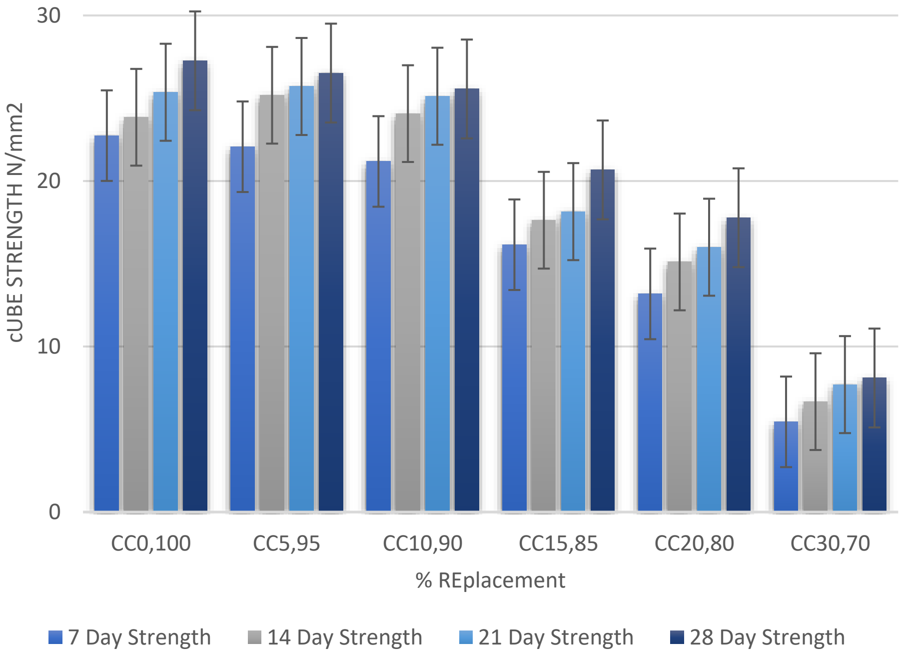

Figure 8. Average compressive strength of concrete cubes

Model

The models developed for the concrete are shown in 2, 3 and 4 equations. For 2, W_D stands for wet density and X_1 stands for percentage replacement level. For 3, D_D stands for dry density, Q_1 stands for curing age in days and Q_2 stands for percentage replacement level while for 4, P_C stands for compressive strength, T_1 stans for curing age in days and T_2 stands for percentage replacement level.

$$W_D = 2413.77 - 4.98X_1 \quad (2)$$

$$D_D = 2485.79 + 2.19Q_1 - 7.35Q_2 \quad (3)$$

$$P_C = 24.09 + 0.19T_1 - 0.63T_2 \quad (4)$$

The regression analysis of the data for models 2, 3, and 4 showed a significant (p =0.0006, 2.1E-08 and 1.4E-12) linear relationship between the parameters. But their R-square values were 0.9, 0.81 and 0.92 respectively which shows a high level of correlation, which means that for model 2, about 90% of the variation in the outcome variable (wet density) was explained by the model. For model 3, about 81% of the variation in the outcome variable (dry density) was explained by the model, while for model 4, about 92% of the variation in the outcome variable (compressive strength) was explained by the model. The remaining 10%, 19%, and 8% respectively is due to random error or other factors. The t-test analysis carried out on the models shows that for model 2, t Stat = -99.21 < t Critical two-tail

= 2.57, for model 3, t Stat = -139.26 < t Critical two-tail = 2.07 while for model 4, t Stat = -2.31 < t Critical two-tail = 2.02.

The null hypothesis is therefore accepted, and alternative hypotheses are rejected for the models. Hence, the models are adequate. This shows that the laboratory concrete densities and concrete cube compressive strength results and the model-predicted concrete densities and concrete cube compressive strength results have no significant difference. Thus, the wet density, dry density, and compressive strength of mass I rice straw ash (MRSA) concrete could be reliably predicted by equations 2, 3, and 4, respectively.

Validation of Models

The proposed models 2, 3, and 4 have proved their validity to be used for predicting the wet density, dry density, and compressive strength of MRSA concrete by yielding high coefficient of correlation (multiple R value) as depicted in table 6. This values of 95%, 90%, and 96% indicates a very strong linear correlation between the various dependent variables and independent variables. The remaining 5%, 10%, and 4% respectively is due to random error or other factors. Also, tables 7, 8, and 9 show the residual output which are the differences between the laboratory obtained values and the model predicted values for models 2, 3, and 4 respectively.

Table 6. Multiple R values for Models 2, 3 and 4

Regression Statistics	
Multiple R (2)	0.950796
Multiple R (3)	0.902162
Multiple R (4)	0.962083

Table 7. Residual Output for model 2

Observation	***Predicted W_D (kg/m³)***	***Residuals***
1	2413.7	-7.7
2	2388.8	-3.8
3	2363.9	-10.9
4	2339.0	16.9
5	2314.1	18.8
6	2264.2	-19.28

Table 8. Residual Output for model 3

Observation	***Predicted D_D (kg/m^3)***	***Residuals***
1	2501.1	18.87
2	2464.3	45.6
3	2427.5	41.4
4	2390.8	9.1
5	2354.0	-53.0
6	2280.5	-38.5
7	2516.4	-37.4
8	2479.6	-30.6
9	2442.9	36.0
10	2406.1	13.8
11	2369.3	30.6
12	2295.8	-44.8
13	2531.7	-52.7
14	2495.0	-7.0
15	2458.2	-8.2
16	2421.4	18.5
17	2384.7	25.2
18	2311.2	38.7
19	2547.1	-9.1
20	2510.3	-2.3
21	2473.5	-14.5
22	2436.8	42.1
23	2400.0	36.9
24	2326.5	-41.5

Table 9. Residual output for Model 4

Observation	***Predicted P_C (N/mm^2)***	***Residuals***
1	25.4	-2.6
2	22.2	-0.2
3	19.1	2.0
4	15.9	0.1
5	12.8	0.3
6	6.5	-1.0
7	26.7	-2.9
8	23.6	1.5
9	20.4	3.5
10	17.3	0.3
11	14.1	0.9
12	7.8	-1.1
13	28.1	-2.7
14	24.9	0.7
15	21.8	3.2
16	18.6	-0.5
17	15.5	0.4
18	9.2	-1.5
19	29.4	-2.2
20	26.3	0.1
21	23.1	2.3
22	20.0	0.6
23	16.8	0.9
24	10.5	-2.4

CONCLUSIONS

This research centred on the utilization of mass-I rice straw ash (MRSA) in producing eco-friendly concrete. MRSA was used in place of OPC at various replacement levels as a supplementary cementitious material. Hence, the conclusions drawn are as follows:

- Chemical composition shows that mass I rice straw ash (MRSA) have combined percentages of (SiO_2 + Al_2O_3 + Fe_2O_3) of 70.49% and the XRD pattern revealed that the MRSA is mainly of an amorphous nature.
- The workability of concrete decreased as the percentage replacement of OPC with MRSA increases.
- The wet and dry density was significantly affected by higher percentage increase in replacement of OPC with MRSA.
- Compressive strength of MRSA concrete increased as the curing age increases.
- Compressive strength of MRSA concrete dramatically decreased with the increase in percentage replacement of OPC.

- The CC5,95 and CC10,90 that is concrete containing 5% and 10% OPC replacement with MRSA, gained compressive strength of 26.52N/mm^2 and 25.56N/mm^2 at 28th day of curing making it an excellent choice for developing eco-friendly structural reinforced grade 25 concrete.
- The models developed with good coefficients of determination was tested and found to be adequate.

A future study approach can be

- Adding MRSA to other agricultural pozzolanas (binary blend, ternary blend, etc.);
- to partially replace OPC Use of machine learning to develop a model for predicting the strength of MRSA concrete;
- Use of MRSA in the production of geopolymer concrete;

CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interests associated with this publication.

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