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1.Alban Chidiebere OGBONNA, 2.Mikailu ABUBAKAR

# APPLICATION OF RICE HUST ASH AS A SUPPLEMENTARY CEMENTITIOUS MATERIAL IN CONTINUOUSLY REINFORCED CONCRETE PAVEMENT CONSTRUCTION

1,2.Department of Civil Engineering, Waziri Umaru Federal Polytechnic, Birnin Kebbi, Kebbi State, NIGERIA

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**Abstract:** Continuously reinforced concrete pavement has the potential to provide a long term, "zero – maintenance" service life under heavy traffic, provided proper design and quality construction practices are utilized. Concrete mixes containing 0%, 5%, 10%, 15%, 20%, 25%, and 30% of rice husk ash was prepared and cured in portable water. The compressive strengths of concrete specimens were evaluated at the 3rd, 7th, 14th, 28th, 56thand 91st day old. The split tensile strength and the flexural strength were evaluated at the 14th and 28th day. The compressive strength values, split tensile strength values and flexural strength values of the concrete specimens increased with increase in age and also increased with increase in 5% and 10% percentage replacement of cement with rice husk ash. The concrete specimens containing 0% to 25% percentage replacement of cement with rice husk ash satisfied the minimum compressive strength requirements specified in the relevant standard specifications and manuals. The study therefore concluded that up to 25% of rice husk ash should be used as partial replacement of cement in continuously reinforced concrete pavement.

**Keywords:** cement, compressive strength, continuously reinforced concrete pavement (CRCP), flexural strength, rice husk ash

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## 1. INTRODUCTION

Continuously reinforced concrete pavement (CRCP) contains continuous longitudinal steel reinforcement without transverse joints, except where required for end-of-day header joints, at bridge approaches, and at transitions to other pavement structures. Continuous reinforcement is a strategy for managing the transverse cracking that occurs in all new concrete pavements. In new concrete pavements, volumetric changes caused by cement hydration, thermal effects, and external drying are restrained by the pavement base layer and longitudinal reinforcement causing tensile stresses to develop in the concrete. These stresses, referred to as restraint stresses, increase more rapidly than the strength of the concrete at early ages of the concrete pavement, so, at some point, full-depth transverse cracks form, dividing the pavement into short, individual slabs. In CRCP, the continuous reinforcement results in internal restraint and produces transverse cracks that are closely spaced with small crack widths that help to maximize the aggregate interlock between adjacent CRCP panels [21].

Continuously reinforced concrete pavement (CRCP) is concrete pavement with steel reinforcing bars with no transverse joints. CRCP is reinforced in the longitudinal direction with additional transverse bars used to support the longitudinal bars as shown in Figures 1a and b. The longitudinal bars are lap spliced to maintain continuity, ensuring continuous reinforcement [19].

Concrete consists of a combination of cementitious materials, coarse and fine-graded aggregate, water, and typically some property modifying admixtures. Concrete properties such as strength, durability, permeability, and abrasive wear resistance are materials dependent. CRCP should be designed using the highest quality concrete materials to maximize long-term durability. Use of rapid strength concrete (RSC) is not recommended [18-22].

In an experiment to determine the Effect of Partial Replacement of Cement by Fly Ash, Rice Husk Ash with Using Steel Fiber in Concrete, [39] concluded that compressive strength increases with the increase in the percentage of Fly ash and Rice Husk Ash up to replacement (22.5%FA and 7.5% RHA) of Cement in Concrete for different mix proportions. The mechanical properties in terms of flexural and tensile strength have been significantly improved with the addition of RHA. Due to addition of rice Husk ash, plasticity of concrete increases and thus permits easier placing and finishing of concrete. It is resistance to chloride ions hence it saves concrete from being corrosive and enhances its life. Rice husk ash at particular concentration is known to increase concrete strength and also gives impermeable characteristics to concrete due to pozzolonic character. Because the RHA have less heat of hydration it reduces the crack formation in concrete. Crack formation is major problem in highways and roads. It increase water permeability can hence destruction of roads easily and early than expected. So RHA concrete leads to less crack formation and less permeability can cause concrete road to stand still for long time [40]. According to [41] addition of pozzolans like rice husk ash to the concrete, can improve the mechanical properties of specimens.

American concrete institute [7-8] defined pozzolan as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divide form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. Natural pozzolan is defined as either raw or calcined natural material that has pozzolanic properties. The natural pozzolans in the raw or calcined state are designated as class N pozzolans and are describe in the specification as " Raw or calcined natural pozzolans that comply with the applicable requirements for the class". Raw or processed natural pozzolans are used in the production of hydraulic-cement concrete and mortars in two ways: as an ingredient of blended cement, or as a mineral admixture [17]. A binary mixture is simply a mixture of two components. But a ternary mixture of cementitious materials, for example the component could be Portland cement, fly ash, and slag. Likewise, the combination could be a blended cement (already a binary mixture) and slag. Binary and ternary mixtures are becoming more prevalent because they can enhance performance and reduce cost. The reduction in cost is associated with the fact that most supplementary cementations materials are by-products. However the used of these materials also decrease the amount of Portland cement that must be manufactured. This makes the cement industry more sustainable [7, 8, 17].

Artificial pozzolans are finely divided cementations material other than Portland cement, consisting of mainly of fly ash, ground blast furnace slag, or silica fume (Micro silica), and have been considered in the production of high-strength concrete because of the required high cementitious materials content and low water cementitious material ratio. These materials can help control the temperature rise in concrete at early ages and may reduce the water demand for a given workability. However early straight gain of the concrete may be decreased (American concrete institute) [9, 17]. This research therefore aims at evaluating the application of rice hust ash as a supplementary cementitious material in continuously reinforced concrete pavement construction.

Figure 1: Continuously reinforced concrete pavement under construction

## 2. MATERIALS AND METHODS

### — MATERIALS

### ≡ Cementitious materials

Hydraulic cement is a material that sets and hardens when it comes in contact with water through a chemical reaction called hydration, and is capable of doing so under water. Hydration is a nonreversible chemical reaction. It results in hydrated cement paste, a strong, stiff material. Hydraulic cements include Portland cement and blended cements. Other types of hydraulic cements are rapid-setting calcium sulfur-alumina cements used for repair materials or for pavements where fast turnaround times are critical [23-38]. Portland cement is the most common hydraulic cement used in concrete for construction. It is composed primarily of calcium silicates, with a smaller proportion of calcium aluminates. The hydraulic cement used in this study conforms to the specifications of [4, 7-10, 23-31].

Supplementary cementitious materials (SCMs) contribute to the strength gain of concrete. However, the amount or rate of this contribution will depend on the chemistry, fineness, and amount of the SCM. Generally, with Class F fly ash and ground, granulated blast-furnace slag, early strengths are lower than those of similar mixtures with Portland cement only, and ultimate strengths are higher. The effect of Class C fly ash will go either way, depending on the specific fly ash used. Silica fume normally increases strengths at both early and later ages (although silica fume is not generally used in concrete for pavements). Mix proportions can be selected to achieve the required strengths with or without the presence of SCMs, but the majority of concrete mixtures include one or more SCMs [28-38]. The rice husk ash used in this research have the same properties with the class F fly ash in line with the specifications of [1, 2, 7, 8, 17] as shown in the Tables 1.

### ≡ Fine and coarse aggregate

Ordinary variations in aggregate grading have little effect on the bleeding of concrete mixtures, provided that there is no appreciable variation in material smaller than 75µm. However, concrete mixtures containing aggregates with a high amount of silt, clay, or other material passing the 75-µm ( No 200) sieve can significantly reduce bleeding, although there may be other adverse effects on the concrete, like increased water requirement and shrinkage. [1, 2, 14].

Granites are igneous rocks composed predominantly of forms of silica (for example, quartz) and silicates (for example, feldspar). The grain or texture varies from fine to coarse. Granites may vary markedly in color and texture within individual quarries, but more commonly the color and texture are uniform for large volumes of rock. Because of its mineral composition and interlocking crystals, granite is hard and abrasion resistant. Its compressive strength typically ranges from 50 to 400 MPa, with the typical value of 165MPa in the dry state. Most granite is capable of supporting any load to which it might be subjected during ordinary construction uses [18-31]. The fine aggregate used in this study is river sand that satisfied the specifications of [3, 5, 6, 16, 31] and, the coarse aggregate used in this study is crushed granites that satisfied the specifications of [3, 16 31].

Table 1. Average chemical composition of rice hust ash and class f fly ash.

| Chemical Composition | Percentage composition (%) | |
|---|---|---|
| | Rice Hust Ash | Class F Fly Ash |
| $SiO_2$ | 88.50 | 66.80 |
| $Al_2O_3$ | 0.09 | 7.20 |
| $Fe_2O_3$ | 2.16 | 13.52 |
| CaO | 0.06 | 5.10 |
| MgO | 0.83 | 2.10 |
| $P_2O_5$ | 0.31 | - |
| $Na_2O$ | 0.07 | 0.9 |
| $K_2O$ | 3.75 | 2.5 |
| LOI | 3.30 | 1.0 |
| $SiO_2+Al_2O_3+Fe_2O_3$ | 90.75 | 87.52 |

## — METHODS

### ≡ Physical properties of fine and coarse aggregate

The sieve analysis was conducted for fine and coarse aggregate in accordance with [14]. The sieves are nested in order of increasing size from the bottom to the top, and the test sample is placed on the top sieve. The loaded sieves are shaken in a mechanical shaker for approximately 10 minutes. Maximum care was taken so that sieves are not overloaded.

The specific gravity and water absorption of the fine and coarse aggregate were conducted in accordance with [2] and [1] respectively. The aggregate crushing value and the Los-Angeles abrasion value tests were conducted for the coarse aggregate in accordance with [ 1, 2, 5, 6, 11, 16, 31].

### ≡ Water – cementitious materials (W/cm) ratio

Water-Cementitious Materials (W/CM) Ratio Strength increases as the w/cm ratio decreases because the capillary porosity decreases. This observation holds for the entire range of curing conditions, ages, and types of cements considered. Remember, however, that although there is a direct relationship between w/cm ratio and strength, concretes with the same w/cm ratio but different ingredients are expected to have different strengths. Table 4 shows the water cementitious materials used in this study [18-31]

### ≡ Mix design and slump test

The concrete mixes were designed and batched in accordance with the specifications of [9, 10, 26, 27] as shown in Table 4. The mixing water confirms with the specifications of [19, 20, 23, 24, 29]. The water cement ratio was maintained at 0.55 and the maximum size of coarse aggregate used was 19mm. The slump test was carried out to determine the consistency of the fresh concrete and it is in conformance with [10, 27, 28, 30] as shown in Table 4.

### ≡ Compressive strength, flexural strength and splitting tensile strength

This test method consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen. The concrete specimens for compressive strength test were of 150mm diameter and 300mm long. The compressive strength of the specimens was evaluated at the 3rd, 7th, 14th, 28th, 56th and 91stday age. The average compressive strength value for each age was recorded as the compressive strength in accordance with the specifications of [6, 10, 18-20, 23, 24, 26-38].

Compression tests of moist-cured specimens were made as soon as practicable after removal from moist storage. Test specimens were kept moist during the period between removals from moist storage and testing and were tested in the moist condition. All test specimens for a given test age were crushed within the permissible time tolerances prescribed by [31].

Three set of specimens were crushed for each percentage replacement at the 3rd, 7th, 14th, 28th, 56th and 91st days. The compressive strength for each specimen and the average compressive strength of the set of specimens were calculated to the nearest 0.1MPa. Equation 1 was used to calculate the average compressive strength of each set of specimens and equation 2 was used to calculate the density of the concrete specimen. The density of the concrete specimen was calculated to the nearest 10Kg/m$^3$.

$$\text{Average compressive strength} = \frac{C1+C2+C3}{3} \quad (N/mm^2) \quad (1)$$

where: CS1 = Compressive Strength of Specimen 1 , CS2 = Compressive Strength of Specimen 2 and CS3 = Compressive Strength of Specimen 3

$$\text{Density} = \frac{W}{V} \quad (kg/m^3) \quad (2)$$

where: W = mass of specimen measured in kilogram (kg), V = volume of specimen computed from the average diameter and average length or from weighing the cylinder in air and submerged, measured in $m^3$.

The splitting tensile strength and the flexural strength were conducted in accordance with [28, 30]. The concrete cylindrical specimens used for the splitting tensile strength test were of 150mm diameter and 300mm long. The flexural strength was conducted using the three point bend test method.

### ≡ Water absorption and voids in hardened concrete

The density, percentage absorption, and percentage voids in hardened concrete for different percentage replacement of cement with groundnut shell ash was determined in accordance with the procedure specified in ASTM C642 (2013) at the 28th, and 91st day of curing. The specimens used were 100mm diameter and 50mm thick cylindrical concrete of volume $393cm^3$ and oven dry mass of 943g. Each portion of the specimens were free from observable cracks, fissures, or shattered edges. Each specimen was oven dried at a temperature of 100 to 110°C for 30 hours. After removing each specimen from the oven, it was allowed to cool in dry air (preferably in a desiccator) to a temperature of 20 to 25°C and the mass was determine and denoted as A. The experiment continued in line with the procedure specified in ASTM C642 (2013) and equations 1-7 are used to calculate water absorption, voids and densities of hardened concrete.

$$\text{Absorption after immersion (\%)} = \left[\frac{(B-A)}{A}\right] X\,100 \quad (1)$$

$$\text{Absorption after immersion and boiling (\%)} = \left[\frac{(C-A)}{A}\right] X\,100 \quad (2)$$

$$\text{Bulk density, dry } (g/cm^3) = g_1 = \left[\frac{A}{C-D}\right] X\,\rho \quad (3)$$

$$\text{Bulk density after immersion } (g/cm^3) = \left[\frac{B}{C-D}\right] X\,\rho \quad (4)$$

$$\text{Bulk density after immersion and boiling } (g/cm^3) = \left[\frac{C}{C-D}\right] X\,\rho \quad (5)$$

$$\text{Apparent density } (g/cm^3) = g_2 = \left[\frac{A}{A-D}\right] X\,\rho \quad (6)$$

$$\text{Volume of permeable pore space or voids, (\%)} = \left[\frac{g2-g1}{g2}\right] X\,100 \text{ or } \left[\frac{(C-A)}{(C-D)}\right] X\,100 \quad (7)$$

where: Volume of concrete sample ($cm^3$) = V, Mass of oven dry sample in air (g) = A, Mass of surface–dry sample in air after immersion (g) = B, Mass of surface-dry sample in air after immersion and boiling (g) = C Apparent mass of sample in water after immersion and boiling (g) = D, Density of water ($g/cm^3$) = $\rho$ = 1

## 3. RESULTS AND DISCUSSION

### — Aggregate characteristics

The most important grading is that of the combined aggregate in a concrete mixture [28-31]. Well-graded aggregate, indicated by grading Table 2 will generally provide better performance than a gap graded system. Table 2 shows the combine sieve analysis results of the fine and coarse aggregate from Table 2 it can be seen that the aggregate used were well graded of 19.00mm maximum size. The results shown in Tables 2 and 3 show that the fine and coarse aggregate used in this study satisfied the specifications of [ 3, 16, 20, 24].

Table 3. Physical properties of fine and coarse aggregate

| S/N | Properties | Fine aggregate | Coarse aggregate |
|---|---|---|---|
| 1. | Specific gravity | 2.61 | 2.73 |
| 2. | Water absorption (%) | 2.10 | 3.0 |
| 3. | Los Angeles abrasion value (%) | - | 29 |
| 4. | Aggregate crushing value (%) |  | 24 |

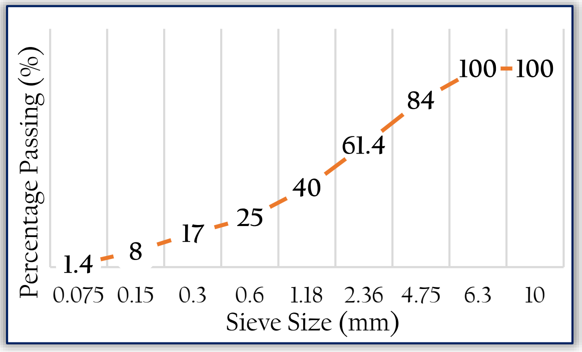

Figure 1a: Sieve analysis of fine aggregate

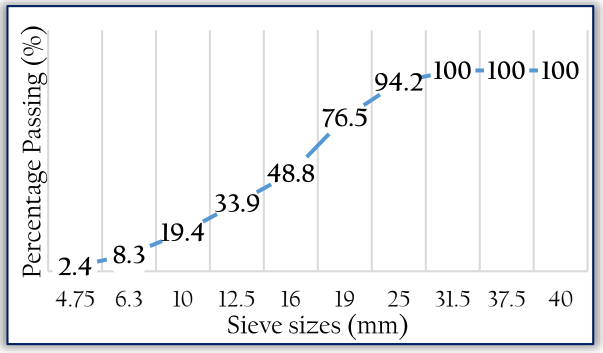

Figure 1b: Sieve analysis of coarse aggregate

— **Concrete mix ratio**

Tables 4 shows the concrete mix design of the specimen containing 0%, 5%, 10%, 15%, 20%, 25%, and 30% replacement of cement with sugar rice husk ash respectively. The water cement ratio in Table 4 was kept content for all specimens. The fine aggregate to total aggregate ratio is 0.4. The physical properties of the aggregates shown in Table 3, the combine sieve analysis results shown in Table 2 and the design mixes shown in Tables 4 conform with the specifications of [9, 10, 19, 20, 23, 24, 26-30] which specified 20% maximum replacement of cement with fly ash or processed pozzolan materials, minimum cement content as 300 to 360 kg/m³ and fine aggregate to total aggregate ration of 0.35 to 0.45 for standard and high performance concrete pavements.

Table 4. Concrete mix design of 1: 2: 3 mix ratio

| Concrete cylindrical specimen mark | Water/ cementitious materials ratio | Cementitious materials Kg/m³ | | Fine Aggregate Kg/m³ | Coarse Aggregate Kg/m³ |
|---|---|---|---|---|---|
| | | Cement | Rice husk ash | | |
| 0D | 0.55 | 400 | 0 | 800 | 1200 |
| 5D | 0.55 | 380 | 10 | 800 | 1200 |
| 10D | 0.55 | 360 | 20 | 800 | 1200 |
| 15D | 0.55 | 340 | 30 | 800 | 1200 |
| 20D | 0.55 | 320 | 40 | 800 | 1200 |
| 25D | 0.55 | 300 | 50 | 800 | 1200 |
| 30D | 0.55 | 280 | 60 | 800 | 1200 |

— **Concrete characteristics**

From Table 5 and Figures 3 and 4 it can be observed that compressive strength of all the concrete specimens' increase with increase in age irrespective of the percentage replacement of cement with rice husk ash. It is observed that 5 to 10% replacement of cement with rice husk ash yield higher compressive strength than the 0% replacement concrete. Concrete specimens containing rice husk ash show increase in slump values and low strengths at early age and higher strength at later age which is in agreement with the properties on natural and processed pozzolan materials stated in [9, 10, 19, 20, 23, 24, 28, 30].

Table 5. Fresh and hardened properties of concrete specimens

| Concrete cylindrical specimen mark | Percentage replacement of cement with rice husk ash (%) | Slump (mm) | Compressive strength N/mm² | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 3 days old | 7 days old | 14 days old | 28 days old | 56 days old | 91 days old |
| 0D | 0 | 78 | 16.47 | 22.06 | 31.89 | 38.87 | 46.80 | 56.05 |
| 5D | 5 | 78 | 13.73 | 19.76 | 30.48 | 39.06 | 48.08 | 59.05 |
| 10D | 10 | 82 | 11.23 | 17.71 | 28.71 | 39.75 | 48.34 | 58.00 |
| 15D | 15 | 88 | 9.69 | 15.01 | 25.12 | 38.08 | 46.11 | 55.80 |
| 20D | 20 | 97 | 8.45 | 13.26 | 24.56 | 35.01 | 42.09 | 51.46 |
| 25D | 25 | 103 | 8.01 | 12.33 | 22.64 | 31.44 | 37.88 | 49.00 |
| 30D | 30 | 109 | 7.30 | 10.34 | 19.01 | 28.05 | 35.00 | 45.33 |

The 28 days compressive strengths of all the concrete specimens containing 0% and 25% replacement of cement with rice husk ash satisfied the minimum compressive strength range of 28N/mm² to 31N/mm²and 31N/mm²to 41N/mm² for standard and high performance concrete pavement as specified by the [9, 10, 19, 20, 24, 26-30]. From Table 6 it can be observed that the splitting tensile strengths and the flexural strengths for all the concrete specimens increase with increase in age and decrease with increase in percentage replacement of cement with rice husk ash.

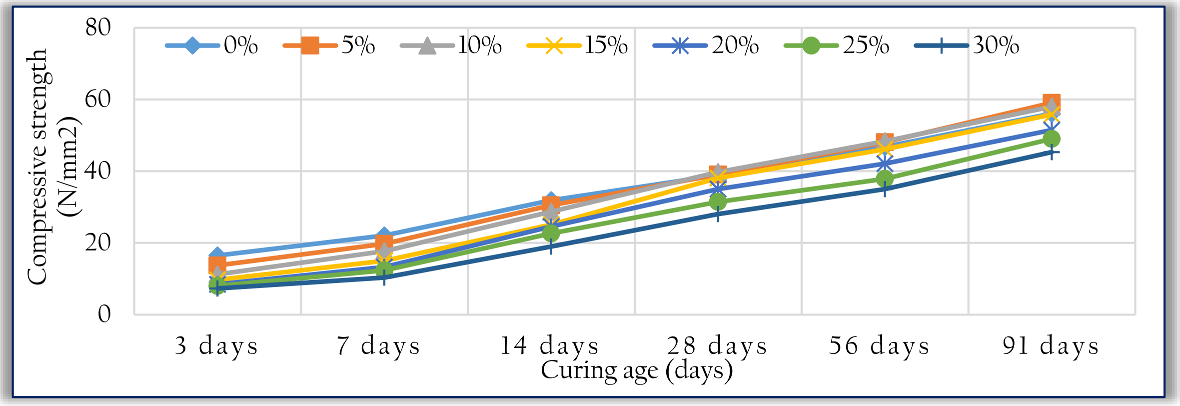

Figure 3. Relationship between the compressive strength and curing age of concrete specimens containing rice husk ash

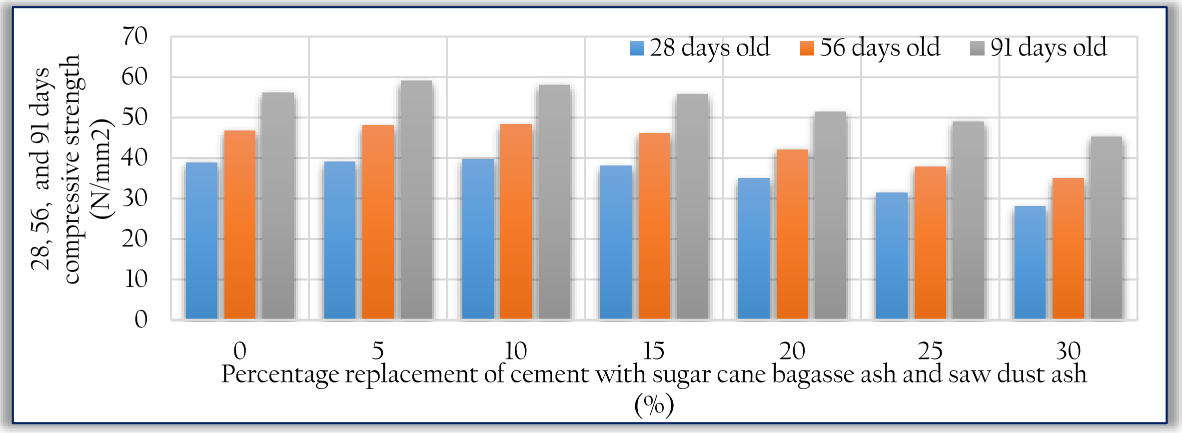

Figure 4. Relationship between the percentage replacement of cement with rice husk ash with 28, 56 and 91 days compressive strength of concrete.

Table 6. 7 days and 28 days splitting tensile strengths and flexural strengths

| Percentage replacement of cement with rice husk ash (%) | Split tensile strength of concrete specimens containing rice husk ash (N/mm$^2$) | | Flexural strength of concrete specimens containing rice husk ash (N/mm$^2$) | |
|---|---|---|---|---|
| | 7 days | 28 days | 7 days | 28 days |
| 0 | 2.98 | 3.09 | 3.11 | 3.50 |
| 5 | 2.33 | 2.40 | 2.68 | 2.84 |
| 10 | 2.10 | 2.21 | 2.41 | 2.61 |
| 15 | 2.04 | 2.11 | 2.26 | 2.34 |
| 20 | 1.69 | 1.91 | 2.00 | 2.18 |
| 25 | 1.37 | 1.59 | 1.82 | 2.00 |
| 30 | 1.23 | 1.39 | 1.51 | 1.78 |

— **Water absorption and voids in hardened concrete**

The specimen use for the Water absorption and Volume of permeable pore space (voids) in hardened concrete at 28th and 91st day curing age satisfied the specifications of [12, 25]. From Tables 7 and 8 and Figure 5 it can be observed that water absorption after immersion, water absorption after immersion and boiling and volume of permeable pore space (voids) decrease with increase in percentage replacement of cement with rice husk ash. This indicates that the concrete containing rice husk ash has reliable durability qualities and will perform favorably if used in continuously reinforced concrete pavement.

Permeability is defined as the ease with which fluids can penetrate concrete [25]. Permeability and water absorption can be lowered by reducing the number of connected pores within the paste system of a mixture. This can be accomplished through a lower water/cement ratio (w/cm), improved curing, and the use of supplementary cementitious materials (SCMs). The boil test measures the volume of permeable pore space in a concrete mixture. Permeability of the concrete in a Portland cement concrete pavement is a major factor for long-term durability. Pavements with low permeability resist penetration of moisture into the concrete matrix, leading to long-term durability.

Table 7: Water absorption and Volume of permeable pore space (voids) in hardened concrete at 28thday.

| S/N | Description and units | Percentage replacement of cement with rice husk ash | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0% | 5% | 10% | 15% | 20% | 25% | 30% |
| 1. | Volume of sample (cm$^3$) | 393 | 393 | 393 | 393 | 393 | 393 | 393 |
| 2. | Mass of oven dry sample in air (g) | 952 | 956 | 960 | 960 | 964 | 972 | 972 |
| 3. | Mass of surface–dry sample in air after immersion (g) | 996 | 994 | 997 | 997 | 991 | 994 | 994 |
| 4. | Mass of surface-dry sample in air after immersion and boiling (g) | 1005 | 1003 | 1002 | 1002 | 1000 | 1002 | 1002 |
| 5. | Apparent mass of sample in water after immersion and boiling (g) | 612 | 610 | 609 | 609 | 607 | 609 | 609 |
| 6. | Absorption after immersion (%) | 4.6 | 4.0 | 3.5 | 3.5 | 2.8 | 2.3 | 2.3 |
| 7. | Absorption after immersion and boiling (%) | 5.6 | 4.9 | 4.4 | 4.4 | 3.7 | 3.1 | 3.1 |
| 8. | Density of water (g/cm$^3$) | - | - | - | - | - | - | - |
| 9. | Bulk density, dry (g/cm$^3$) | 2.42 | 2.43 | 2.44 | 2.44 | 2.45 | 2.47 | 2.47 |
| 10. | Bulk density after immersion (g/cm$^3$) | 2.53 | 2.53 | 2.54 | 2.54 | 2.52 | 2.53 | 2.53 |
| 11. | Bulk density after immersion and boiling (g/cm$^3$) | 2.56 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 |
| 12. | Apparent density (g/cm$^3$) | 2.8 | 2.76 | 2.74 | 2.74 | 2.70 | 2.68 | 2.68 |
| 13. | Volume of permeable pore space or voids, (%) | 13.8 | 12.0 | 11.0 | 11.0 | 9.3 | 7.8 | 7.8 |

Table 8: Water absorption and Volume of permeable pore space (voids) in hardened concrete at 91st day.

| S/N | Description and units | Percentage replacement of cement with rice husk ash | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0% | 5% | 10% | 15% | 20% | 25% | 30% |
| 1. | Volume of sample ($cm^3$) | 393 | 393 | 393 | 393 | 393 | 393 | 393 |
| 2. | Mass of oven dry sample in air (g) | 952 | 956 | 960 | 960 | 964 | 972 | 972 |
| 3. | Mass of surface–dry sample in air after immersion (g) | 986 | 984 | 982 | 982 | 984 | 989 | 989 |
| 4. | Mass of surface-dry sample in air after immersion and boiling (g) | 993 | 992 | 990 | 990 | 988 | 992 | 992 |
| 5. | Apparent mass of sample in water after immersion and boiling (g) | 600 | 599 | 597 | 597 | 595 | 599 | 599 |
| 6. | Absorption after immersion (%) | 3.6 | 2.9 | 2.3 | 2.3 | 2.1 | 1.8 | 1.8 |
| 7. | Absorption after immersion and boiling (%) | 4.3 | 3.7 | 3.1 | 3.1 | 2.5 | 2.1 | 2.1 |
| 8. | Density of water ($g/cm^3$) | - | - | - | - | - | - | - |
| 9. | Bulk density, dry ($g/cm^3$) | 2.42 | 2.43 | 2.44 | 2.44 | 2.45 | 2.47 | 2.47 |
| 10. | Bulk density after immersion ($g/cm^3$) | 2.51 | 2.50 | 2.50 | 2.50 | 2.50 | 2.52 | 2.52 |
| 11. | Bulk density after immersion and boiling ($g/cm^3$) | 2.53 | 2.52 | 2.52 | 2.52 | 2.51 | 2.52 | 2.52 |
| 12. | Apparent density ($g/cm^3$) | 2.71 | 2.68 | 2.65 | 2.65 | 2.61 | 2.61 | 2.61 |
| 13. | Volume of permeable pore space or voids, (%) | 10.7 | 9.3 | 8.0 | 8.0 | 6.1 | 5.3 | 5.3 |

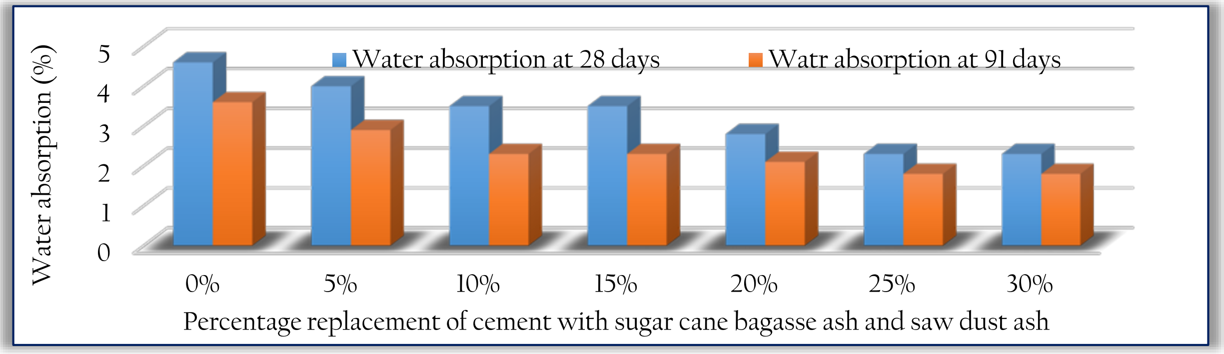

Figure 5: Water absorption after immersion in hardened concrete at 28th and 91st days curing age (%)

## 4. CONCLUSIONS

The following conclusions were made at the end of this study:

- Concrete specimens containing up to 25% of rice husk ash show significant increase in slump values and in later days compressive strength.
- Concrete specimen containing up to 25% of rice husk ash satisfied the minimum compressive strength range of 31N/mm² to 41N/mm² for high performance concrete for continuously reinforced concrete pavement and other types of concrete pavement as specified by the [9, 10, 18-21, 23, 24, 26-30].
- A binary mix containing rice husk ash should be used where available in continuously reinforced concrete pavement.
- The use of binary mixes should be encouraged. They are cost effective considering the quantity of cement that will be saved. Binary mixtures also ensure sustainable cement and concrete industries.
- Binary batched concrete specimens containing rice husk ash have low water absorption and low permeable pore spaces (voids). This indicates good durability properties.

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