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# Recyclable Potential of Rice Husk Ash as Partial Replacement of Cement for Rigid Pavement

***Ikponmwen Daniel Osamudiamen*and Ogbeifun, Nowamagbe Prince***
Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria
*Corresponding author: ikponmwendaniel@gmail.com

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**Abstract**

*Significant environmental impact caused by the high $CO_2$ emissions during cement production has placed a climate change burden on the construction industry being the major consumer of cement. This has led to the exploration of alternative materials, such as Rice Husk Ash (RHA), a by-product of rice milling with high silica content, as a partial substitute for cement in concrete. Nigeria has been experiencing rapid urbanization and extensive road construction. This Study investigated the use of RHA in rigid pavement construction, evaluating its effects on workability, compressive strength, flexural strength, and splitting Tensile strength with 10%, 15%, 20%, 25%, and 30% replacements. The slump test revealed that as RHA content increased, workability decreased. Furthermore, 10% replacement of cement with RHA achieved the highest performance, with a 28-day compressive strength of 32.089 MPa, surpassing the design target of 30 MPa. Flexural strength at this level also met the required minimum of 3.18 N/mm². However, higher replacement levels (20–30%) resulted in significant reductions in strength which indicates diminished structural reliability. Although the peak splitting tensile strength of 2.38 MPa was achieved at 15% RHA replacement, all mixes except for the 30% replacement remained within the 2–5 MPa range recommended for rigid pavement applications. Overall, RHA-modified concrete with up to 10% replacement demonstrates potential for rigid pavement use in road construction*

## 1. Introduction

The construction industry is one of the major consumers of natural resources, particularly cement, which is a major constituent in concrete production. However, the increasing cost of cement and the associated environmental pollution caused by its production have fostered numerous research efforts towards finding a material that can partially or fully replace cement. In 2021, the production of cement from several countries worldwide was over 3.5 billion tonnes and the value went up to over 5.5 billion tons in 2050 [1]. Cement is a vital building material, but its production comes with a significant environmental cost, as it emits a substantial amount of $CO_2$ into the atmosphere. It has been observed that for every unit of cement produced, an equal amount of $CO_2$ is released into the atmosphere, accounting for over 5% of all human-made carbon emissions [2, 3].

Rice husk is a by-product of rice milling and is typically disposed of as agricultural waste. Oyetola and Abdullahi [4] reported that close to 100 million tonnes of rice husk are generated annually worldwide. The Food and Agricultural Organization (a unit of the United Nations) stated that Nigeria produces over 8 million tonnes of rice annually, and with an average of 20% rice husk content, the estimated rice husk generation in 2024 is expected to be around 1.2 million tonnes [5, 6]. since the production of Rice Husk Ash (RHA) in the country has not been commercialized, this quantity of rice husk is mostly disposed of by open air burning that possess environmental hazard.

Rice husk ash (RHA) is primarily composed of a significant amount of silica, along with varying amounts of other elements and carbon residues resulting from incomplete combustion. The high concentration of amorphous silica in RHA makes it a suitable material for partial replacement of ordinary Portland cement (OPC), offering a promising alternative for sustainable construction practices. The silica content varied between 54.65% and 90.45% across the different rice husk ash (RHA) samples in Nigeria [7, 8]. Other promising materials which have been studied for the use in road construction include steel and polypropylene fibers [9] and ceramic dust [10]. The Availability of Rich husk in Nigeria, which currently constitutes a waste product, can be harnessed for use in road pavement construction which take up a sizeable portion of the federal annual budget for capital project with potential for some cost reduction.

The construction industry is experiencing rapid growth globally, with a significant increase in cement demand making the annual concrete production worldwide to be around 12 billion tons and this uses up approximately 1.6 billion tons of Portland cement [11]. The primary raw material of Ordinary Portland cement, limestone, may face a potential shortage in the next 25 to 50 years, posing a significant concern for the industry's sustainability. Moreover, the production of cement involves processes that release large amounts of greenhouse gases, including the heating of calcium carbonate, fuel combustion and limestone preparation. As a result of the aforementioned, the cement industry is the second-largest contributor to carbon dioxide emissions in the industrial sector[12]. These emissions have severe environmental and health consequences, including acid rain, global warming, health risks, reduced crop yields, and loss of biodiversity.

Concrete has become increasingly important in Nigeria's highway construction due to its durability, strength, and lower maintenance requirements compared to asphalt. As urbanization and industrial activities expand, there is a growing need for more resilient and long-lasting road infrastructure. According to Pandit *et al.* [13], rigid pavements are increasingly favoured in national highway construction due to their enhanced durability, superior flexural strength, and ability to support heavy axle loads. They also offer longer service life and perform more effectively under harsh environmental conditions compared to other pavement types. This shift toward concrete-based highway infrastructure reflects Nigeria's commitment to sustainable development and the construction of roads that can meet the demands of modern transportation.

The properties of concrete produced by replacing cement with rice husk ash was studied by Valli and Dhevasenaa [14]at different levels of 10%, 20%, and 30%, with a range of curing periods from 7 days, 14 days, and 28 days.. The experimental work suggested that cement could be replaced with RHA up to a maximum limit of 10%.

In a study carried out by Tan *et al.* [15], eggshell powder was incorporated in varying proportions specifically 5%, 10%, 15%, and 20% by volume as a partial replacement for ordinary Portland cement. Based on the results obtained, it was concluded that the most effective and optimal proportion of oven-dried eggshell powder for enhancing the performance of the cement mix is 15%. At this percentage, a favorable balance between strength and material efficiency was achieved, making it the recommended level for partial cement substitution in similar applications.

Ahangba and Michael [16] employed corn cob ash (CCA) as a partial replacement for cement in concrete mixtures, using varying ratios of 5%, 10%, 15%, 20%, and 25%. To evaluate the effects on strength, concrete cubes were cast and cured for 7, 14, and 28 days. Based on the test results, it was concluded that CCA can be effectively used as a partial cement substitute in concrete production, especially for non-load-bearing applications such as wall panels and other light construction works. However, it was recommended that the replacement level should not exceed 10%, as higher proportions resulted in a decline in strength that may not meet the required structural standards.

This research is centred on investigating the potential use of concrete that has been modified with rice husk ash, with the primary goal of evaluating its effectiveness and performance for use in rigid pavement applications. The study aims to determine whether the inclusion of rice husk ash can enhance the properties of concrete in a way that meets the structural and durability requirements necessary for rigid pavement construction.

## 2. Materials and Method

### 2.1 Materials

The materials to be used in this research include Rice Husk Ash, fine aggregate, Coarse Aggregate, cement and distilled water.

#### 2.1.1 Rice Husk Ash

The rice husks were sourced from suppliers in Edo State, Nigeria, to ensure a consistent and high-quality raw material. The rice husks were burned in a controlled manner in a blast furnace at the University of Benin's Structural Engineering Laboratory (as shown in figure 1). The burning process was precisely conducted within a carefully calibrated temperature range of 500°C to 700°C to optimize the chemical composition of the resulting ash[17].

After thermal treatment, the resulting rice husk ash was carefully collected and subsequently ground into finer particles using a mortar and pestle, thereby enhancing its reactivity and surface area. The particles were then sieved through a 75µm sieve, strictly adhering to the guidelines outlined in BS 812-103.1:1985. This meticulous sieving process effectively eliminated impurities and larger particles, yielding a finely textured ash suitable for further applications.

**Figure 1: Rice Husk Ash Sample**

#### 2.1.2 Water

Water played an important role in concrete production (mix) in that it started the reaction between the cement, pozzolan, and the aggregates, and it helped in the hydration of the mix. Throughout the research, distilled water served as the primary source of hydration to minimize impurities and optimize results[18].

### 2.1.3 Cement
The study utilized standard Ordinary Portland Cement of grade 42.5, obtained from suppliers in Ugbowo, Benin City, to guarantee uniformity in the test results.

### 2.1.4 Aggregate
This study utilized River sand as fine aggregates and crushed coarse aggregates, which were readily available in the local market, to ensure representative results. Specifically, the fine aggregates were limited to a maximum size of 5 mm, and the crushed coarse aggregates did not exceed 20 mm, conforming to BS 1881: Part 108: 1983.

## 2.2 Mix Design
### 2.2.1 Determination of Target Mean Strength
In accordance with the Federal Ministry of Works-Highway Manual Part 1: Design (1997), the specified compressive strength for rigid pavement typically falls within the range of **30 - 35 N/mm².** However, due to the inherent variability in concrete production, it is necessary to design the concrete mix with a mean strength greater than the specified characteristic strength to ensure structural reliability and performance[19].

$$f_m = f_c + k*s \quad (1)$$

Where;
$f_m$ = the target mean strength ; $f_c$ = the specified characteristic c strength; k = a constant (taken as 1.64 for a 5% defective level); s = standard deviation
$f_m$= 30 + 1.64*5
$f_m$= 38.2 N/mm$^2$

### 2.2.1 Determination of Water-Cement Ratio
A Suitable graph to determine the water-cement ratio from the target strength of concrete was obtained from [19]. The target strength of38.2N/mm$^2$ strength gave 0.53 as the corresponding water-cement ratio (See Figure 2).

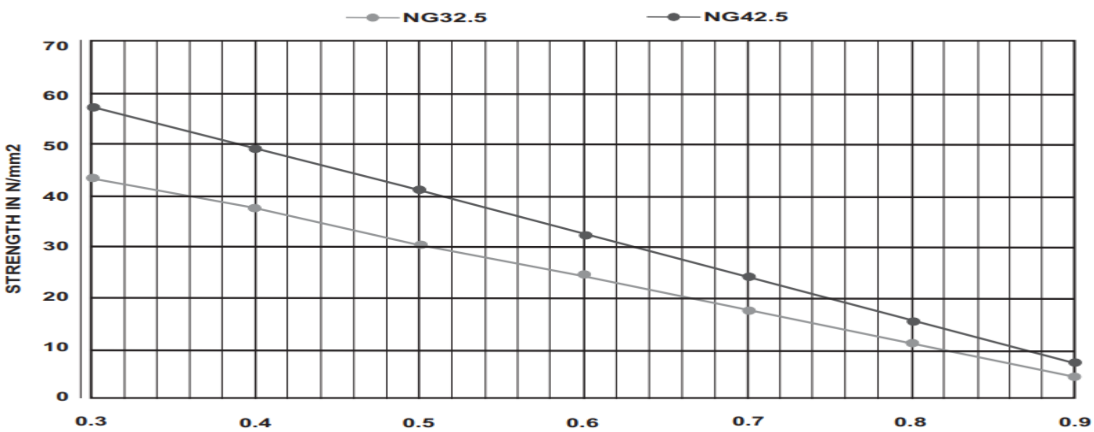


**Figure 2: Strength versus Water/Cement Ratio for Nigerian Cements. (NO. COREN/2017/016/RC)**

### 2.2.2 Determination of Water Content

A maximum crushed coarse aggregate size of 20 mm as stipulated in [19]was used for this investigation, in accordance with standard practice for concrete mix design. Additionally, a **slump** range of 60–180 mm was adopted to achieve the desired workability and ensure ease of placement during the experiment. This resulted in a water content value of 235**kg/m$^3$**, as determined from Table 1 below.

**Table 1: Approximate Free water contents required to give various levels of workability (COREN/2017/016/RC)**

| MAXIMUM SIZE OF COARSE AGGREGATE | AGGREGATE TYPE | SLUMP 30 - 60 | SLUMP 60 - 180 |
|---|---|---|---|
| 20 | **UNCRUSHED** | 180 | 205 |
| | **CRUSHED** | 210 | 235 |
| 40 | **UNCRUSHED** | 160 | 185 |
| | **CRUSHED** | 190 | 215 |

### 2.2.3 Determination of Cement Content

The cement content is determined from the water-cement ratio and the quantity of water with the formula below.

$$\text{Cement content} = \frac{\text{Free water content}}{\text{Free water} - \text{cement ratio}} \tag{2}$$

$$\text{Cement content} = \frac{235}{0.53} = 443.40 \text{ kg/m}^3$$

### 2.2.4Determination of Aggregate Content

To determine the total aggregate content, an estimate of the density of the fully compacted concrete should be known. From tests carried out, a density value of 2400kg/m$^3$ is recommended for use for all mixes using normal weight aggregates.

Total aggregate = 2400 – (water content + cement content) (3)

Total aggregate = 2400 – (235 + 443.40)

Total aggregate = 1721.6 kg/m$^3$

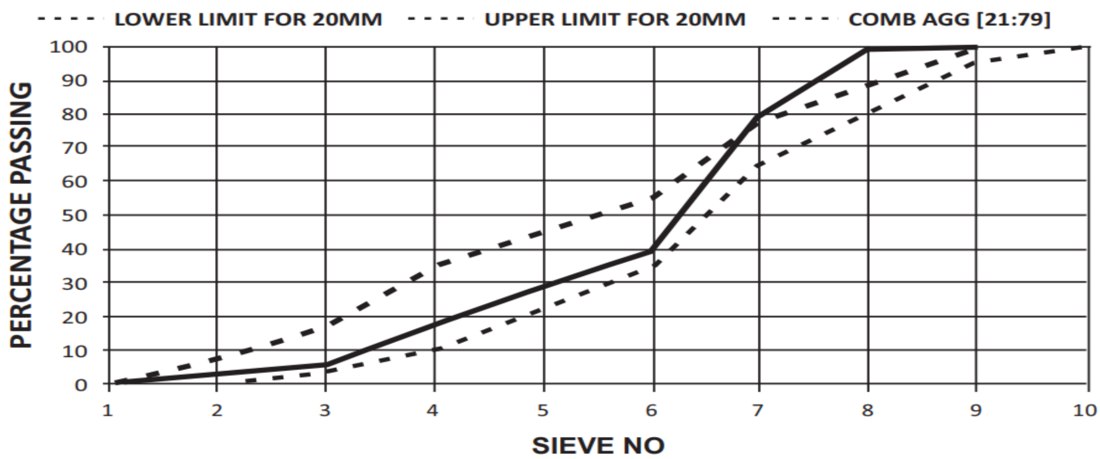


**Figure 3: Combined aggregate grading curve for 21% fines and 79% coarse**

From the graph, the percentage passing corresponding to sieve No 5.5 is 35%.

Fine aggregate= % passing * Total aggregate (4)
Fine aggregate= 35% * 1721.6 kg/m$^3$
Fine aggregate= 602.56 kg/m$^3$
Coarse aggregate = Total Aggregate – Fine Aggregate (5)
Coarse aggregate = 1721.6 – 602.56 = 1119.04 kg/m$^3$
Following the calculation of material proportions, the mix ratio for cement, fine aggregate, and coarse aggregate was established as 1:1.36:2.59, respectively.

### 2.2.6 Curing
After the casting process, all specimens were cured in water for varying durations of 7, 14, and 28 days as stipulated by [19]**,**to maintain optimal moisture levels, which are crucial for enhancing the strength of the material over time. To ensure the accuracy and reliability of the results, special care was taken to use different water tank for the curing process. Specifically, the water used for curing the control specimens (with 0% replacement) was kept distinct from the water used for the cubes containing Rice Husk Ash (RHA), preventing any potential cross-contamination or inaccuracies in the results.

## 2.3 Laboratory Testing Procedure
### 2.3.1 Aggregate Crushing Value Tests
This test was carried in line with **BS812-110:1990,** which gave details regarding the sample preparation, approach to filling the cylinder, compression loading of 400 kN at a rate of 40 kN/min, sieving and weighing procedures. BS Sieve 2.36mm was generally used to recover useful samples for which the fraction passing the sieve is weighed. The Aggregate crushing value ACV is therefore with the formula shown in equation (6). Typical values of

$$ACV = \frac{W_2}{W_1 - W} \times 100 \quad (6)$$

Where; W = weight of empty cylinder; $W_1$ = weight of residue plus weight of cylinder; $W_2$= weight of aggregates that passed the 2.36mm sieve

The general specifications for ACV values ascribed to materials used in rigid pavement are presented in figure 4.

| | |
|---|---|
| ACV | Good Aggregate <45% |
| | Wearing Course <30% |

**Figure 4:Compression Test on Cubes in the Laboratory [20]**

### 2.3.2 Slump Test
The slump test in the study followed the procedures outlined in BS 1881: Part 102:1983. This test can yield three types of slump results: true slump, shear slump, and collapse slump as shown in figure 5**.** A true slump is observed when the concrete settles uniformly while largely retaining its original shape—this is the only result deemed valid for evaluating concrete consistency. In contrast, a shear slump occurs when the upper section of the concrete slips sideways, indicating insufficient cohesion within the mix. A collapse slump, where the concrete completely falls apart, typically signals that the mixture is overly wet or possesses very high workability. If either a shear slump or a collapse slump is recorded, the test must be redone. Notably, a collapse slump suggests an excess of water or a mix designed for extremely high workability. According to Millard (1993), The slump should not exceed **75mm** to be used for concrete pavement [21].

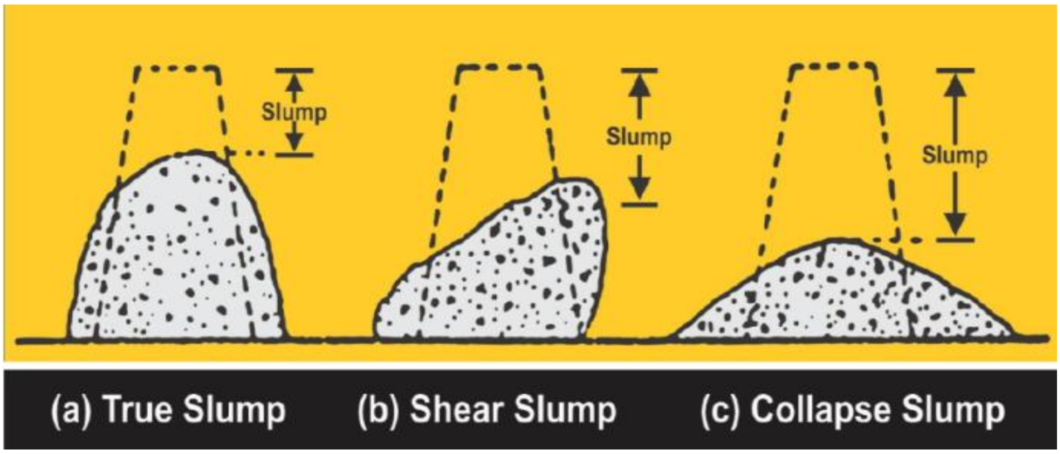


**Figure 5:Compression Test on Cubes in the Laboratory [22]**

### 2.3.3 Compression Strength Test

Concrete cubes with a target strength of 30 MPa were prepared and cast into 100 mm × 100 mm × 100 mm cubes. Proper vibration was applied during casting to ensure compaction. Testing was carried out in accordance with BS 1881 Part 116:1983. Rice Husk Ash (RHA) was used as a partial replacement for cement at varying percentages of 10%, 15%, 20%, 25%, and 30%, while maintaining a constant water-cement ratio of 0.45. A total of 54 cubes were cast and cured in clean water to ensure proper hydration. Compressive strength tests were conducted at curing ages of 7, 14, and 28 days using the standard compression testing machine shown in figure 6. The compressive strength (C) of each cube was calculated using the equation (7) and then rounded to the nearest 0.5 MPa (or $N/mm^2$). The nearness of the resulting compression strength to the target strength is a pointer to the quality of concrete produced from the RHA replacement

$$C = \frac{P}{A} \tag{7}$$

Where; C = compressive strength $N/mm^2$; P = Failure load (N); A = cross sectional area ($mm^2$)


**Figure 6: Compression Test on Cubes in the Laboratory.**

### 2.3.4 Flexural Strength Test

The modulus of rupture parameter in rigid pavement is obtained from the Flexural strength after 28days of curing. The flexural strength of the concrete was evaluated by conducting Two-point bending tests on prisms, each measuring 100 mm by 100 mm in cross-section and 500 mm in length, at curing ages of 7, 14, and 28 days for each mix. This test was performed in accordance with the guidelines outlined in B.S. 1881 Part 118:1983. A universal testing machine as shown in figure 7 was employed to carry out the procedure, ensuring a consistent loading rate during the test to accurately assess the concrete's flexural strength at the specified curing ages. The flexural strength (Modulus of Rupture) R (in N/mm$^2$) was computed using equation (8).

$$R = \frac{PL}{bd^2} \quad (8)$$

Where;
R = Flexural strength (MPa or N/mm²); P = Maximum applied load (N); L = Span length (mm)
b = Width of the beam (mm); d = Depth of the beam (mm)

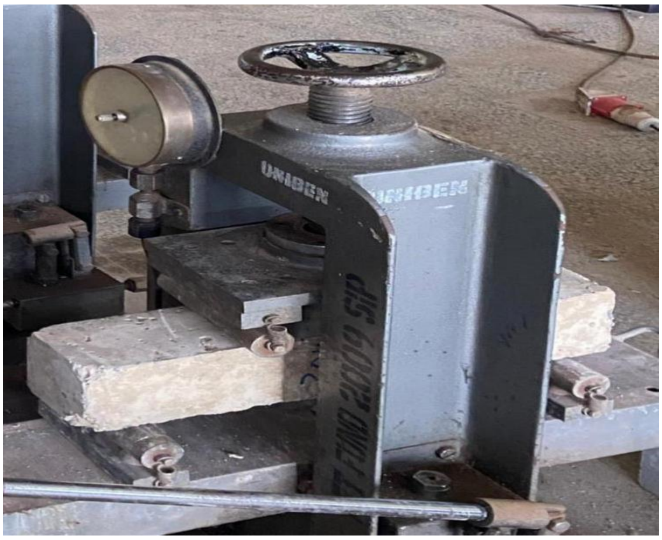


**Figure 7: Flexural Test on Concrete Beam.**

Flexural strength of rigid pavement concrete that makes for adequate construction can be obtained from Section 03300 [23] as presented in Table 2. Millard (1993) gave a relationship between Modulus of rupture (M) and compressive strength (C) for gravel-made after 28days of curing as shown in equation (9). According to Millard [21], with concrete of compressive strength 42 N/mm2 at 28 days, the corresponding moduli of rupture is 3.8 N/mm$^2$ with gravel aggregate.

**Table 2: Modulus of rupture value of concrete for rigid pavements Section 03300 [23]**

| Type | Cube Strength after 28 days [ MPa] | Minimum Quantity of cement Kg per m$^3$ of concrete | Maximum permissible Water/ cement Ratio |
|---|---|---|---|
| **C15** | 15 | 250 kg cement type II | 0.4 |
| **C28** | 28 | 250 kg cement type II | 0.4 |
| **C35** | 35 | 250 kg cement type II | 0.4 |

$$M\left(N/mm^2\right) = 0.49 \times C^{0.55} \quad (9)$$

### 2.3.5 Splitting Tensile Test

The splitting tensile strength of the concrete was evaluated by performing a diameter compression test on cylindrical specimens with varying percentages of RHA (0%, 10%, 15%, 20%, 25%, 30%), each measuring 150 mm in diameter and 300 mm in height, at curing ages of 7, 14, and 28 days for each mix. This test was conducted in accordance with the guidelines specified in B.S. 1881 Part 121:1983.Fapohunda *et al.* [24], the splitting tensile strength of rigid pavement concrete typically ranges from 2 to 5 MPa (approximately 300 to 700 psi), which is roughly 8% to 14% of the compressive strength. A compressive testing machine was used to apply a load along the diameter of the cylinder, ensuring a uniform loading rate throughout the procedure to accurately assess the concrete's splitting tensile strength at the designated curing ages. The Splitting Tensile strength $F_t$ (in $N/mm^2$) was computed using equation (10).

$$F_t = \frac{2P}{\pi DL} \qquad (10)$$

Where;$F_t$ = Splitting tensile strength (MPa or $N/mm^2$); P = Maximum load at failure (N); D = Diameter of the specimen (mm); L = Length of the specimen (mm)

## 3. Result and Discussion

### 3.1 Aggregate Crushing Value Tests

The Aggregate Crushing Value (ACV) obtained for the coarse aggregates used in this study was 28.5%**,** which falls within the acceptable range for materials intended for concrete in rigid pavement applications provided by [20]. According to AASHTO [20], aggregates with an ACV less than 30% are considered to possess adequate strength for use in rigid pavement concrete subjected to moderate to heavy traffic loading conditions.

**Table 3: ACV Test Result for Coarse Aggregate**

| ACV TEST RESULT | | |
|---|---|---|
| | Sample A (g) | Sample B (g) |
| **$M_1$** | 2805.6 | 2806.8 |
| **$M_2$** | 792 | 823.4 |
| **$M_3$** | 2011 | 1981.4 |
| **LOSS** | 2.6 | 1.5 |
| **ACV(%)** | **28** | **29** |

### 3.2 Slump Test

Figure 8 shows the results of the slump tests carried out on the concrete mixes. The data reveal a clear trend of decreasing workability with increasing Rice Husk Ash (RHA) content. The control mix (0% RHA) achieved the highest slump value of 100 mm, while all other mixes with RHA replacement recorded slump values below 75 mm which is generally considered not suitable for rigid pavement (Millard 1993). The slump value at 10% RHA mix was of 71mm though slightly less than the 75mm benchmark can be considered fairly adequate for rigid pavement construction as opposed to the 30% RHA mix with relatively low slump value of 37 mm.

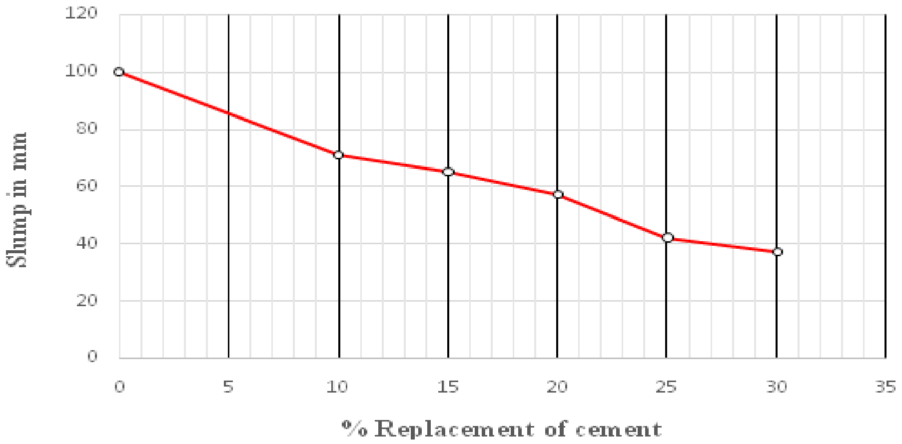

**Figure 8: Slump Test Result**

### 3.3 Compression Strength Test

The results from the concrete mix design shown in Figure 9 indicate that the incorporation of Rice Husk Ash (RHA) as a partial replacement for cement has varying effects on the compressive strength of the concrete. The mix was designed to achieve a minimum strength of 30 N/mm², and after 28 days of curing, the concrete with 10% RHA replacement exceeded this design value, with a compressive strength of 32.089Mpa. This suggests that up to 10% RHA replacement can enhance the mechanical properties of the concrete, potentially improving its durability and performance in rigid pavement application. In contrast, higher replacement percentages of 15%, 20%, 25%, and 30% RHA resulted in compressive strengths that fell below the design strength of 30 N/mm². These reductions in strength could negatively affect the concrete's structural integrity, making it more susceptible to cracking and failure under load. Such concrete may not perform optimally under the heavy traffic loads and environmental stresses typical of rigid pavements.

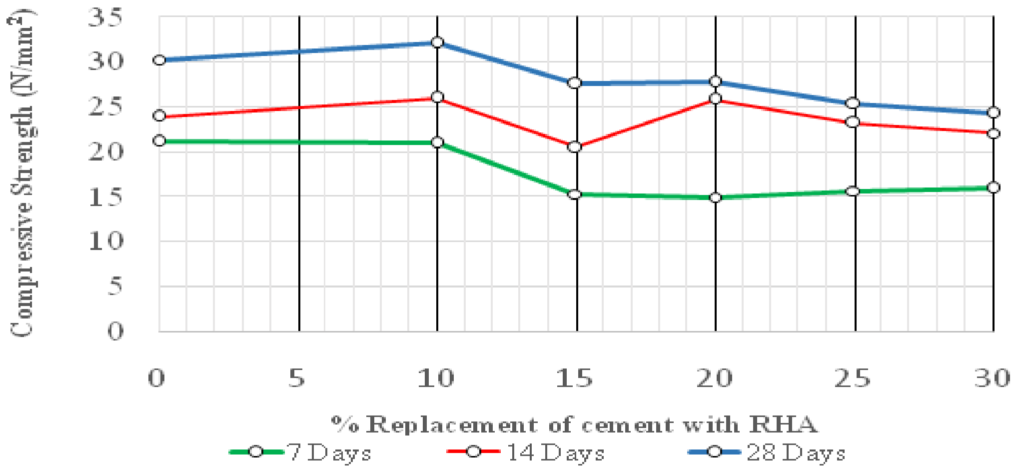


**Figure 9: Compression Test Result**

### 3.4 Flexural Strength Test

Figure 10presents the variation in flexural strength at 7, 14, and 28 days for different percentages of Rice Husk Ash (RHA) replacement. The results 28 days (modulus of Rupture) indicate a slight increase in flexural strength as the RHA content increased from 0% to 10%. However, beyond 10% replacement, a significant decrease in flexural strength was observed. At 28 days, the mixes with 0%, 10% and 15% RHA replacement met the required minimum standard of 3.18 N/mm² given by Millard [21] for flexural strength of Concrete grade 30Mpa, unlike the mixes with 20% to 30% RHA replacement, which fell below this threshold. Since flexural strength is a critical parameter for evaluating concrete performance, especially for rigid pavements, these findings suggest that concrete modified with up to 15% RHA can be a viable and effective material for such structural applications.

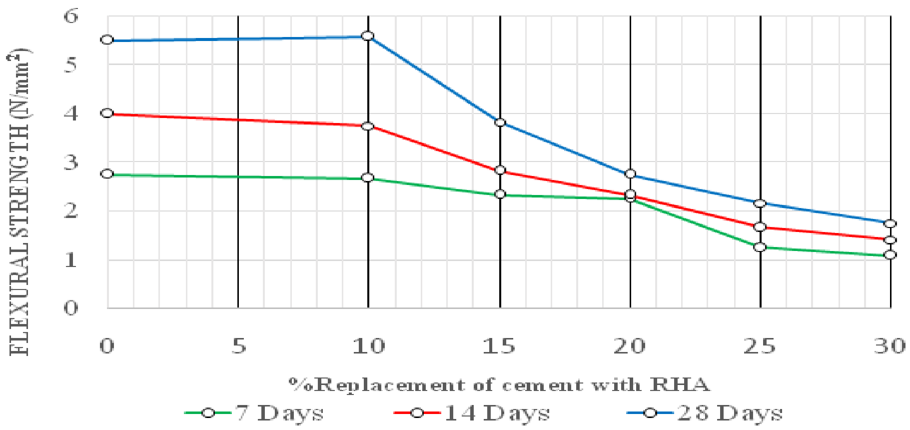


**Figure 10: Flexural Strength Result**

### 3.5 Splitting Tensile Test

The splitting tensile strength results, illustrated in Figure 11**,** display a varied trend based on the percentage of Rice Husk Ash (RHA) used as a partial substitute for Ordinary Portland Cement (OPC). This test was carried out to determine the indirect tensile strength of the concrete and to evaluate the effect of RHA on this key mechanical property. Among all the mixes, the 15% RHA replacement achieved the highest tensile strength, measuring 2.38 MPa. All mixes, except 30% RHA replacement, met the recommended tensile strength range of 2–5 MPa for rigid pavement applications, as suggested by Fapohunda *et al.* [24].

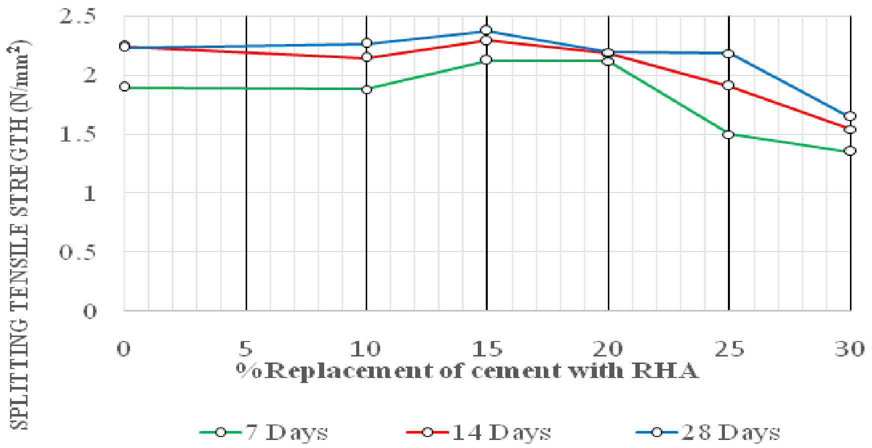


**Figure 11: Splitting Tensile Test Result**

## 4.0 Conclusionand Recommendation.

This study evaluated the impact of Rice Husk Ash (RHA) as a partial cement replacement in concrete for rigid pavement applications. The results showed that a 10% RHA replacement provided the best overall performance, achieving a 28-day compressive strength of 32.089 MPa, exceeding the 30 MPa target. Flexural strength also met the required 4.5 N/mm² at this level. However, higher RHA contents (20–30%) led to reductions in both compressive and flexural strengths, making them unsuitable for structural pavement use.

Although the peak splitting tensile strength of 2.38 MPa was achieved at 15% RHA replacement, all mixes except for the 30% replacement remained within the 2–5 MPa range recommended for rigid pavement applications, suggesting adequate tensile performance and a reduced likelihood of cracking. Concrete with up to 10% RHA showed promising mechanical properties and may be suitable for rigid pavements.

Further study is recommended to enhance the applicability and performance of RHA-modified concrete in rigid pavement construction. Long-term durability tests under real pavement conditions should be conducted to evaluate the material's resistance to environmental stresses, cracking, and wear over time. It is also important to investigate the effects of varying water-cement ratios, as this could help optimize both the strength and workability of RHA-modified concrete for broader structural applications.

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