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Experimental Investigations on Lightweight Aggregate Concrete using Rice Husk Ash

Harish. M.L.[1], Dr. Latha M. S.[2], Dr. M. B. Ananthayya[3], Kadamkumar.S.[4]

[1] *Assistant professor Department of Civil Engineering, Ramaiah Institute of Technology, Bangalore, Karnataka, India*
[2] *Professor Department of Civil Engineering Sri Venkateshwara College of Engineering Bangalore, Karnataka, India*
[3] *Professor Department of Civil Engineering Sai Vidya Institute of Technology Bangalore, Karnataka, India.*
[4] *Post graduate student Department of Civil Engineering, Ramaiah Institute of Technology Bangalore, Karnataka, India.*

Abstract:- In this study, the ideal amount of replacement for rice husk ash (RHA) is produced by burning rice husk at a temperature of 500 °C, as a blending component in cement, has been determined. The initial step was to analyze RHA's physical and chemical characteristics. The study looked at using artificial cinder particles to develop a lightweight aggregate concrete. The study's objective is to produce sustainable lightweight aggregate concrete and evaluate its mechanical and durability properties. The compressive strength, tensile strength, and flexural strength increased when cement was replaced by 20% RHA. The water permeability decreased when cement was replaced by 20% RHA due to the reduction in air content.

Keywords*: Rice Husk Ash, cinder, Lightweight aggregate concrete, mechanical characteristics, durability characteristics.*

1. Introduction

Concrete is a widely utilized construction material in civil engineering structures. When OPC (Ordinary Portland cement) is mixed with water, it will become a strong bonding agent by forming a CSH gel through the hydration process. Cement and water are mixed with sand, and natural coarse aggregate, which, after curing, can be used as a manmade rock. [29]

Demand in the construction industry today is increasing as building materials prices, such as cement and steel are rising. When natural aggregate, such as limestone, granite, etc., are used, the concrete component becomes heavier on its own, increasing the structure's dead load. Experimental studies of different kinds have been done in an attempt to reduce the density of the concrete which has led to the innovation of lightweight aggregate concrete. [24]

Lightweight aggregate concrete is composed of shale, clay, LECA, cinder, and pumice, which results in a lower density with a minimum crushing strength of 17MPa after 28 days of curing. Building energy consumption, like carbon footprints, has grown enormously with time, providing the possibility for the development of suitable materials to lower the carbon footprint using lightweight aggregate concrete. Lightweight aggregate concrete offers the benefits of reduced density, superior durability, and great acoustic insulation. [31]

When compared to regular concrete, having a density of approximately 2500 kg/m3, lightweight aggregate concrete has a low density varying from 1440 kg/m3 to 1900 kg/m3 due to the creation of a significant number of air pockets. [31]

Composition of lightweight aggregate concrete is in line with the conventional concrete, without considering the lightweight aggregates or both lightweight aggregates and natural aggregates. The fine aggregates are replaced by lightweight products in lightweight aggregate concrete in a few cases. By using porous aggregates or by introducing large voids within the mortar or concrete we can classify it as lightweight concrete. [30]

There is a reduction in stiffness of lightweight aggregate concrete when compared with normal concrete of similar strength, however, this is due to the lightweight aggregate concrete's low weight, resulting in a minor reduction in slab or beam depth. [24]

When the deflection of a beam or slab was analyzed, there was a reduction in elastic modulus for lightweight aggregate concrete when compared with regular concrete with similar strength. However, this weakness is due to the lightweight concrete's low weight. [24]

When it comes to long-term consequences, shrinkage and creep are the most essential features of any type of concrete. When compared to equal regular weight concrete, lightweight concrete shrinks and creeps more. This attribute must be considered when developing a structure. [24]

Cinder is a derivative that is produced by burning coal in steel and iron manufacturing industries. Depending on the chemical content, cinder can be black, brown, or red. Density of the concrete ranging between 100 kg/m³ and 1400 kg/m³ can be produced when cinder bring into play as replacement for coarse as well as fine aggregate: however, because sand is frequently incorporated to improve workability, the density of the concrete produced will be in the range of 1750 to 1850 kg/m³. [19]

Countries that produce rice have access to the waste product known as rice husk, which has a 30 to 50 percent organic carbon content. The rice husks are detached from the raw grain using a standard milling process to reveal the full grain of brown rice. After the coating is removed by milling, white rice is created. The current estimated global rice output is 700 million tons. [18]

You can locate rice husk ash in nations that grow rice, such as China, India, and the Middle East countries. A prior study revealed that RHA, in its amorphous state, may be used as a pozzolanic material and is appropriate for partial replacement due to its high silica ($SiO2$) concentration of more than 90%. RHA's chemical makeup varies depending on the incineration process. It is suitable to produce RHA that contains more than 80% amorphous silica by appropriately controlling the burning of rice husk ash at a temperature of 700 °C.

The primary goal of the investigation is to create a long-lasting lightweight aggregate concrete by partly substituting cement with RHA and coarse aggregate with artificial cinder to quantify the reduction in density, carbon footprint, cost of concrete, steel, and self-weight when lightweight aggregate concrete is used in place of regular concrete, as well as to access the mechanical and durability properties.

2. Materials Used

2.1 Cement

In all of the combinations, OPC of grade 53 was utilized. The most vital component for building construction is cement, a popular binding substance. Using IS 269:2015 as a guide, the cement underwent testing. The fineness of cement was 6% with a relative density of cement of 3.15. Its initial and final setting time was 108 minutes and 275 minutes.

2.2 Coarse Aggregate

The aggregates used in this investigation were 20mm down size, with a relative density of 2.74 and a water absorption of 1.23%.

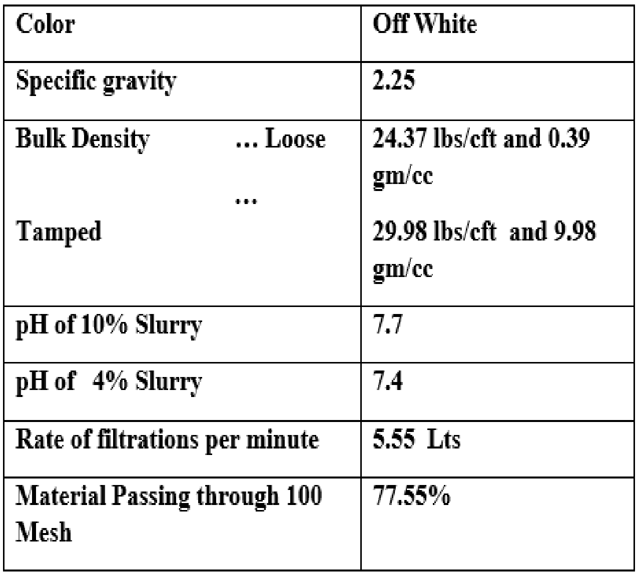
2.3 Fine Aggregate

The fine aggregate utilized for this investigation was M-sand, that has a relative density of 2.7 with water absorption rate of 0.7%, respectively. The fineness modulus of M-sand was 3.49.

2.4 RHA

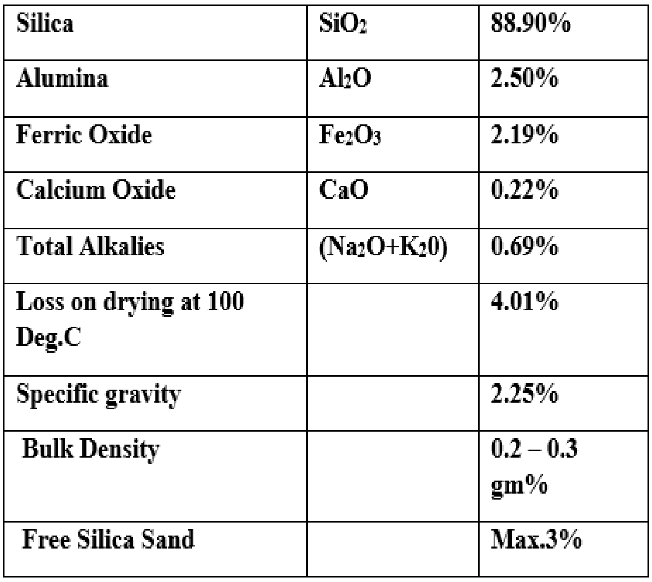
One of the most typical agricultural wastes is rice husk ash, which possesses considerable pozzolanic qualities. Rice husk is transformed into ash form by incineration process under controlled or uncontrolled combustion at a temperature between 600°C to 700°C. Using an open-heap village burning technique, rice husk was first reduced to ash at temperatures between 300 °C and 450 °C. The silica content in the ash may convert into an amorphous phase after being burnt for one hour at temperatures between 550 °C and 700 °C.

Table 2.1: Physical properties of RHA



Color	Off White
Specific gravity	2.25
Bulk Density ... Loose ... Tamped	24.37 lbs/cft and 0.39 gm/cc 29.98 lbs/cft and 9.98 gm/cc
pH of 10% Slurry	7.7
pH of 4% Slurry	7.4
Rate of filtrations per minute	5.55 Lts
Material Passing through 100 Mesh	77.55%

Table 2.2: Chemical properties of RHA



Silica	SiO_2	88.90%
Alumina	Al_2O	2.50%
Ferric Oxide	Fe_2O_3	2.19%
Calcium Oxide	CaO	0.22%
Total Alkalies	(Na_2O+K_20)	0.69%
Loss on drying at 100 Deg.C		4.01%
Specific gravity		2.25%
Bulk Density		0.2 – 0.3 gm%
Free Silica Sand		Max.3%

2.5 Artificial Cinder

The byproduct from burning coal in the steel and iron industries is called cinder. Cinder's relative density was 2.05 and its water absorption rate was 2.51%.

2.6 Water

The water-cementitious material ratio used in this investigation is 0.3.

2.7 Superplasticizer

Fosroc Chemicals India Pvt. Ltd's commercially available superplasticizer, Conplast SP430, was utilized in both conventional and lightweight concrete. Conplast SP430 is a brown liquid that dissolves rapidly in water and is made from sulfonated naphthalene polymers. Conplast SP430 satisfies ASTM-C-494 Types "F" and "A" depending on the doses used. The relative density of superplasticizer is 1.225.

3. Methodology

Structural lightweight aggregate concretes are investigated in this chapter by making use of cinder aggregate as a partial substitute for natural coarse aggregate, while cement was partly replaced with rice husk ash for approximately 5%, 10%, 15%, and 20%.

Before the actual experimental work on the project began, various trail mixes were prepared to get the requisite design mix of M45 grade by varying the water-cement ratio along with the change in percentage of superplasticizer. After obtaining the required design mix, we proceeded with the project.

The first experimental work carried out was the optimization of the mixes replacing normal coarse aggregate partially with cinder and cement with RHA concerning strength and density. The optimized mix here is set with the parameter that it should give low density along with higher compressive strength. Hence cubes of 100mm and 150mm size were cast and tested for 7 and 28 days. Totally 48 cubes were cast. 8 cubes (3 cubes for 7 days and 5 cubes for 28 days) for each different ratio of Rice Husk Ash. The cubes were cured and put through compression testing. The optimum and most appropriate combination is chosen for future study from the findings of the optimization procedure.

Here totally 24 cube specimens of 100mm were developed for compression test, 24 cylinder specimens for split tensile test and 24 prisms for flexural test were adopted. In order to find out the compressive strength and fractural strength, tests were conducted according to IS 516 -1959. In addition, testing were performed in compliance with IS code 5816-1999 to establish the Split tensile strength.

The following experimental effort involves two trials, one assessing water absorption and the other measuring water penetration, to establish the durability characteristics of structural lightweight aggregate concrete. This was accomplished by casting, curing, and testing 150 mm cubes in compliance with the relevant standards; a more detailed study of these standards may be found in the chapter that follows.

Table 3.1: Methodology Adopted

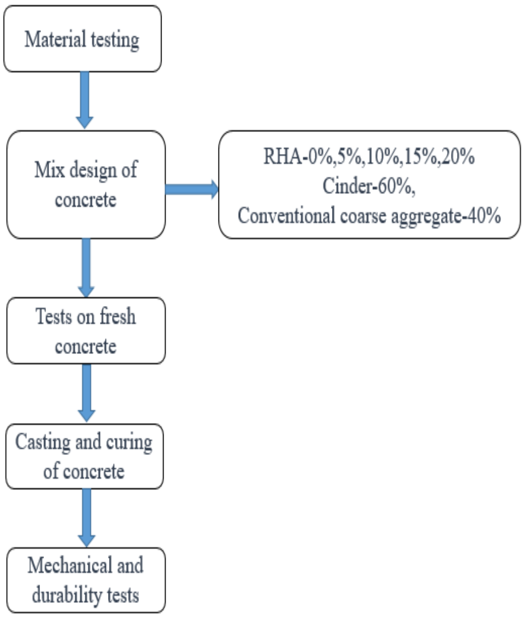
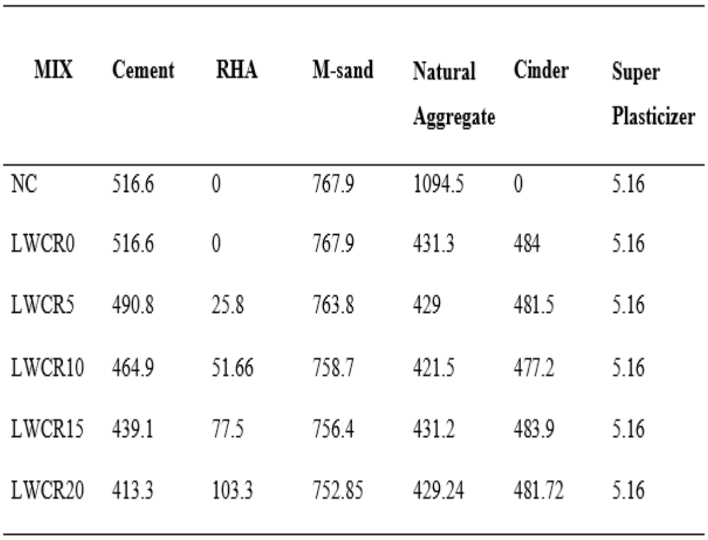


Table 3.2: Mix proportions for various mix (kg/m³)



MIX	Cement	RHA	M-sand	Natural Aggregate	Cinder	Super Plasticizer
NC	516.6	0	767.9	1094.5	0	5.16
LWCR0	516.6	0	767.9	431.3	484	5.16
LWCR5	490.8	25.8	763.8	429	481.5	5.16
LWCR10	464.9	51.66	758.7	421.5	477.2	5.16
LWCR15	439.1	77.5	756.4	431.2	483.9	5.16
LWCR20	413.3	103.3	752.85	429.24	481.72	5.16

3.1 Test Procedure

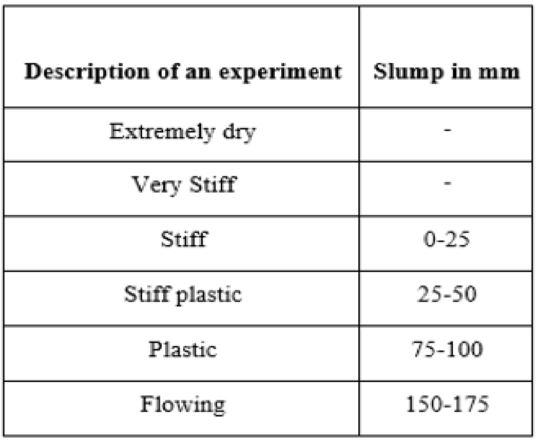
In this project, the slump test was considered as a workability test criteria. 100mm cube specimens were used to test the compressive strength of lightweight aggregate concrete after 7 and 28 days. Tensile strength tests on lightweight aggregate concrete were performed at 7 and 28 days with (100 x 200mm) cylinder specimens. The flexure test was conducted using (150 x 450mm) prism specimens after 7 and 28 days. The average value of two specimens for each testing at 7 and 28 days were recorded. Permeability testing was performed on 150 mm cube specimens after 28 days to detect the water penetration depth in concrete.

4. Results and discussion

4.1 Slump Test Results

A slump value of more than 125 mm suggests extremely liquid concrete, whereas one of less than 25 mm indicates concrete that is exceedingly stiff. Table 4.1 displays the outcomes of the laboratory slump test.

Table 4.1: Comparison of workability values



Description of an experiment	Slump in mm
Extremely dry	-
Very Stiff	-
Stiff	0-25
Stiff plastic	25-50
Plastic	75-100
Flowing	150-175

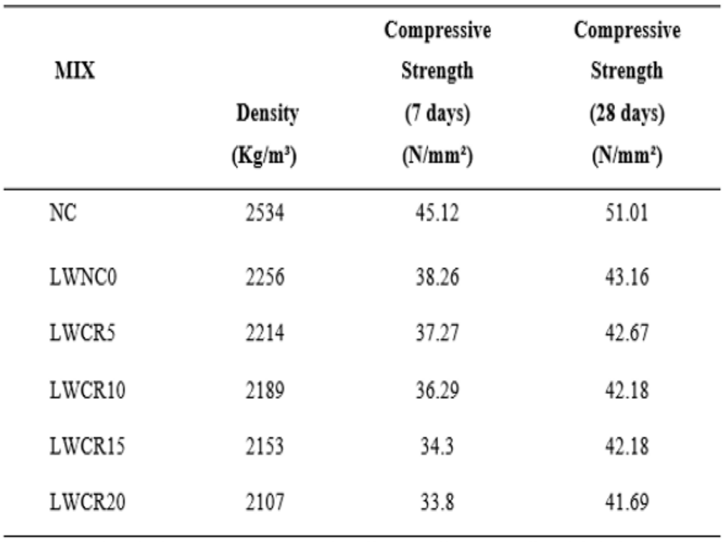
4.2 Air entrapped

The findings of the trials revealed that RHA replacement ratios aided in the reduction of air content. As the cementitious components grew in concentration, the air content decreased. When compared to all mixtures, the RHA substitution ratio of 20% from a cement concentration of 516.6 kg/m3 gradually lowered the air content by 1%.

4.3 Compressive strength

The findings of the compression test may be qualitatively correlated to a number of other properties of concrete, making it the simplest test that can be carried out on the concrete. It is often suggested to use cubes that are 150 mm in size for this test. Three specimens must be cast for each category of sample and testing age, ideally from several batches. After demoulding, the cubes should be stored for curing in a tank where they will be completely immersed. Then, on that particular test day, the cubes are removed (7, 28 each). The cube's surface must be dried and the grit must be removed before testing. The examination followed IS 516-1959 guidelines. The compressive strength of six different combinations was tested, and the findings are displayed in Table 4.2 and Figure 4.2.1.

Table 4.2: Comparison strength of different mixes



MIX	Density (Kg/m³)	Compressive Strength (7 days) (N/mm²)	Compressive Strength (28 days) (N/mm²)
NC	2534	45.12	51.01
LWNC0	2256	38.26	43.16
LWCR5	2214	37.27	42.67
LWCR10	2189	36.29	42.18
LWCR15	2153	34.3	42.18
LWCR20	2107	33.8	41.69

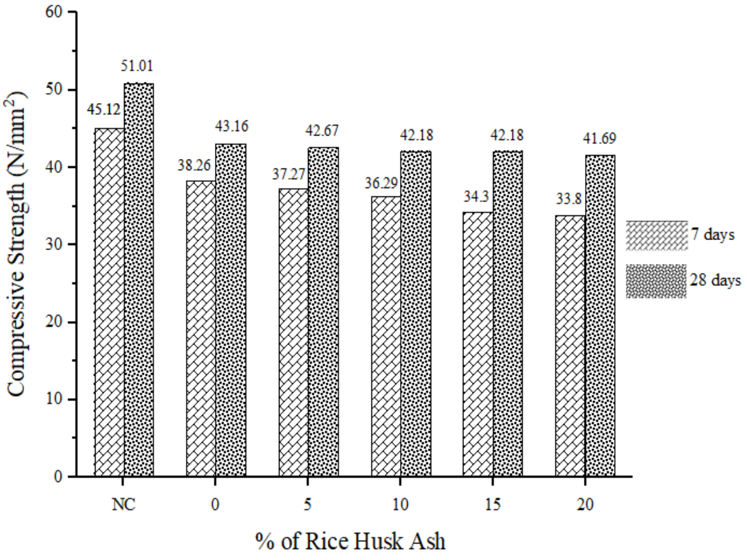


Fig 4.2.1. Graphical Representation of Comparison strength for different concrete mixes

4.4 Tensile Strength

For this test, cylinder specimens of 100 mm in diameter and 200 mm in length are used to find out the tensile strength of the concrete mixes. In comparison to the compressive strength of concrete, this test has less value since concrete is weak in tension. The factors influencing the tensile strength of structural lightweight aggregate concrete (SLWAC) are shown in Table 4.3. In contrast to how SLWAC concrete behaves in compressive strength, it behaves entirely differently in tensile strength. The compressive strength of LWCR20 concrete has fallen when compared to LWCR0 concrete, however, the split tensile strength of LWCR20 concrete has improved when compared to LWCR0 concrete. The main reason for this behaviour would be that the Rice Husk Ash could have absorbed energy when they are stretched in tension.

Table 4.3: Tensile strength of different concrete mixes

MIX	Tensile Strength (7 days) (N/mm²)	Tensile Strength (28 days) (N/mm²)
NC	3.75	4.37
LWCR0	2.54	3.75
LWCR5	2.54	3.5
LWCR10	2.86	3.18
LWCR15	3.02	3.5
LWCR20	3.18	4.06

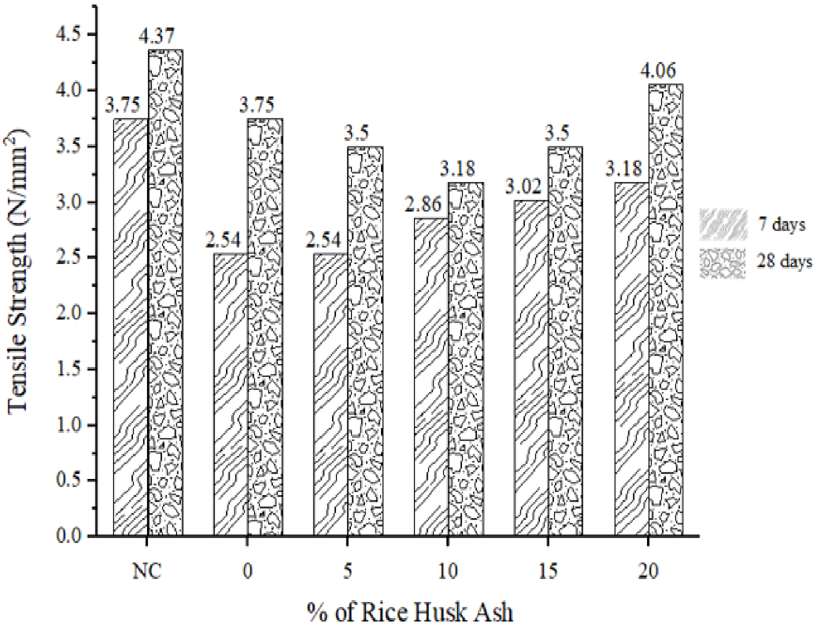


Fig 4.3.1. Graphical Representation of Tensile strength for different concrete mixes

4.5 Flexure Strength

The flexural test specimen must be a standard 450mm x 450mm x 75mm dimension. Three specimens, ideally from different batches, must be made for testing at each selected age. Tests must be conducted on test specimens at known ages; the most typical age is 28 days. According to Table 4.4, there are many similarities between the tensile test results and how SLWAC concrete behaves when it comes to flexural strength. The flexural strength of LWCR20 has increased somewhat when compared to LWCR0, which might be attributed to the increased quantity of rice husk ash, which is better at absorbing stress from flexural bending.

Table 4.4: Flexure strength of different concrete mixes

MIX	Flexure Strength (7 days) (N/mm²)	Flexure Strength (28 days) (N/mm²)
NC	6.02	7.08
LWCR0	5.84	6.19
LWCR5	5.75	6.11
LWCR10	5.66	6.02
LWCR15	5.75	6.28
LWCR20	5.93	6.64

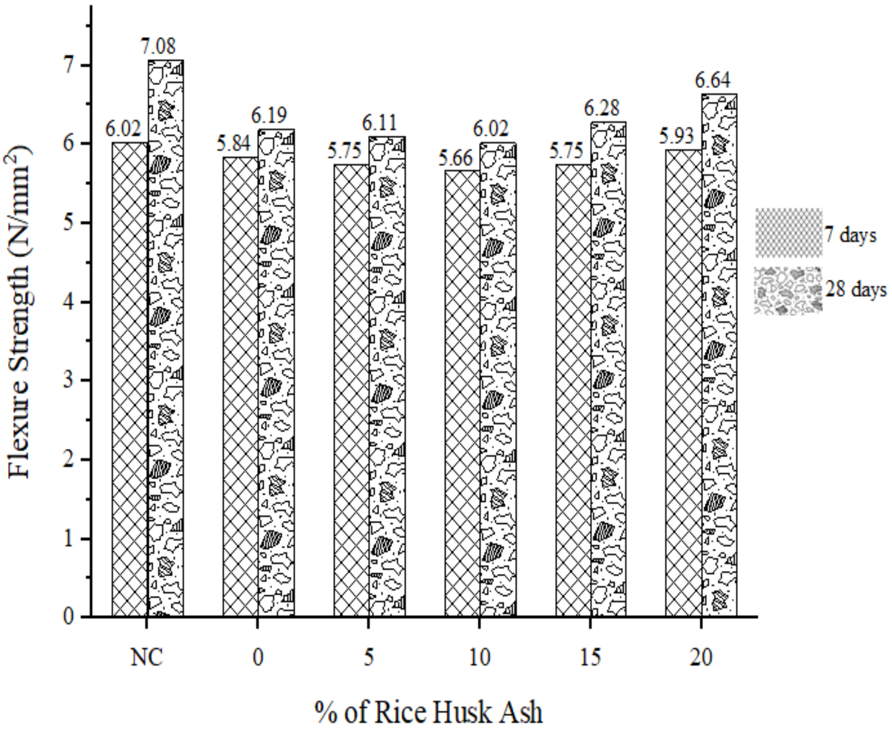


Fig 4.4.1. Graphical representation of flexure strength for different concrete mixes

4.6 Water Absorption

To carry out this test twelve cubes of size 100mm are tested, out of which two specimens in each proportion. The specimen's dry weight is indicated as w1g. The specimen is then washed off with a towel and weighed again as w2g after being immersed in water for 48 hours. The average percentage of water absorption of concrete with various ratios of Rice Husk Ash to natural coarse aggregate and cinder is calculated. The results are given in Table 4.5 below.

Table 4.5: Water Absorption for different mixes (28 days)

Mix	Dry weight in Kg	Wet weight in Kg	% of water absorption
NC	2.423	2.47	1.88
LWCR0	2.11	2.21	4.52
LWCR5	2.067	2.17	4.75
LWCR10	2.05	2.14	4.21
LWCR15	2.007	2.11	4.88
LWCR20	1.975	2.08	5.05

Figure 5.8.1 shows that the water absorption of NC is substantially lower than that of the different LWCRs. The percentage of water absorption increased gradually when the amount of RHA increased, which can be seen in the graph.

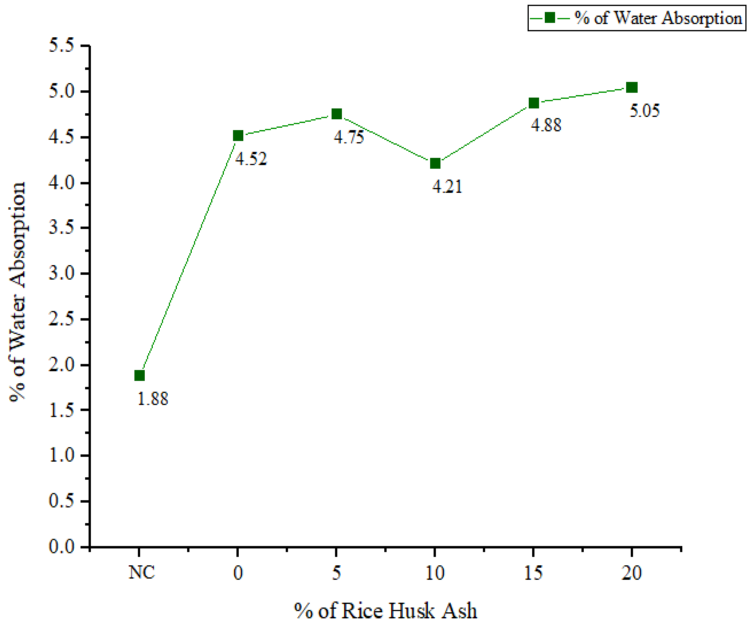


Fig 4.5.1. Graphical representation of water absorption for different concrete mixes (28 days)

4.7 Permeability

The BS 12390 code was followed in conducting this test: Hardened concrete test: water's depth of penetration. 150 mm cube samples were used as the test specimens in this experiment, and they were subjected to a constant pressure of 5 bar for 72 hours. The specimens were then removed, split in half, and the front's greatest depth of water penetration was recorded. The results of the depth of water penetrated in each specimen are shown in table 4.6.

From below results, the depth of water penetrated in SLWAC concrete prepared using 20% Rice Husk Ash is nearer to the normal concrete. While LWCR20 concrete has a 10 mm water penetration depth, NC concrete only has a 6 mm water penetration depth.

Table 4.6: Permeability Test results for various mixes (28 days)

MIX	Depth Of Penetration (28 days) mm
NC	6
LWCR0%	28
LCR5%	26
LCR10%	16
LCR15%	14
LCR20%	10

5. Conclusions

- The percentage reduction in density is about 18% when comparing Lightweight aggregate concrete containing 20% of Rice Husk Ash (LWCR20) with normal concrete (NC).
- The LWCR20 concrete has a minimal compressive strength reduction of about 3.4% with minimal increment in tensile and flexure strength when compare with Lightweight aggregate concrete without Rice Husk Ash (LWCR0).
- When compared to ordinary concrete, LWCR20 concrete has a compressive strength reduction of about 18% with a minimal reduction in tensile and flexure strength of about 7%.
- The water absorption of LWCR20 is about 5.05% and the depth of penetration is 11mm which can be considered as a very good quality concrete.
- When compared to ordinary concrete, the carbon footprint is reduced by about 33.03 percent.
- When compared to ordinary concrete, the material cost is reduced by around 2.75 percent.
- When compared to ordinary concrete, the percentage reduction in self-weight and steel is approximately 10% and 21%, respectively.

6. Future scope of study

- The bond strength of the SLWAC shall be investigated.
- For SLWAC, other durability tests like fire resistance, chemical attacks, and some non-destructive techniques shall be investigated.
- The investigation of properties like Poisson's ratio and Young's modulus is required.

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[31] ACI-213R-2014, “Guide for Structural Lightweight-Aggregate Concrete”.