

Study on concrete with partial replacement of cement by rice husk ash

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Abstract. Increase in the demand of conventional construction materials and the need for providing a sustainable growth in the construction field has prompted the designers and developers to opt for 'alternative materials' feasible for use in construction. For this objective, the use of industrial waste products and agricultural byproducts are very constructive. These industrial wastes and agricultural byproducts such as Fly Ash, Rice Husk Ash, Silica Fume, and Slag can be replaced instead of cement because of their pozzolanic behavior, which otherwise requires large tract of lands for dumping. In the present investigation, Rice Husk Ash has been used as an admixture to cement in concrete and its properties has been studied. An attempt was also done to examine the strength and workability parameters of concrete. For normal concrete, mix design is done based on Indian Standard (IS) method and taking this as reference, mix design has been made for replacement of Rice Husk Ash. Four different replacement levels namely 5%, 10%, 15% and 20% are selected and studied with respect to the replacement method.

1.Introduction

Concrete is identified as the source of a nation's infrastructure due to its economic progress and strength, and indeed to the superiority of life. Over 5% of global CO₂ emissions can be credited to Portland cement production. To reduce the limitations of cement (OPC), it can be partially replaced with green materials which have pozzolanic characteristics. Number of green materials has been studied for the replacement of cement partially like fly ash, ground nut shell ash, etc. which have been successful. The present paper focuses on the replacement of cement partially with Rice Husk Ash (RHA). India is one of the leading producers of Rice. Globally rice paddy of about 600 million tons is being produced, accounting for an annual production of 120 million tons Rice Husk. In most of the cases, the husk produced during the processing of the rice is either burnt or dumped as waste material. Rice husk ash contains 90%-95% of reactive silica. It is estimated that the world rice harvest is about 588 million tons per year and India is the second largest producer of rice in the world with a production of 132 million tons per year annually. Extensive research has been carried out on the use of amorphous silica in the manufacture of concrete. Most of these studies have been performed in order to find the effectiveness of RHA as a pozzolan by concentrating on the amount of ash present in the mix and on the enhanced characteristics resulting from its use.



The influence of particle size effect on the strength of rice husk ash mixed with gap-graded Portland cement concrete was discussed by Bui et.al [1]. They found that replacement of the cement partially up to 20% RHA by mass results in enhanced early-age compressive strength in the gap-graded binder mixtures. Analysis on optimum level of replacement for strength and durability properties of concrete was discussed by Ganesan et.al [2], Gemma Rodri'guez de Sensale [3], Hwang Chao-Lung et.al [4]. Study about strength characteristics of high strength rice husk ash concrete was discussed by Ravande Kishore et.al [5]. They found that increase in the replacement of cement by RHA in concrete decreases the concrete workability by a slump of 27% and compaction factor of 9%. The optimum replacement level of Rice Husk Ash is found to be 10% for both M20 and M30 grades of concrete. Tashima, M.M et.al [6] discussed about the possibility of adding Rice Husk Ash (RHA) to the concrete and Rama Rao, G.V. et.al [7] discussed about the high strength concrete with RHA as mineral admixture. Carbon neutral off-White Rice Husk Ash as a replacement for white cement partially was discussed by Rossella, M.Ferraro et.al [8]. They observed that due to the presence of high amorphous silica and large specific surface area, OWRHA is an efficient pozzolanic material which can also be used as a supplementary cementing material. Percentage of OPC, upto 15% by weight, can be replaced with OWRHA without causing any undesirable effect on the strength properties. Reactivity of rice husk ash was discussed by James J et.al [9] and observed that addition of RHA to the cement reduces the formation of $\text{Ca}(\text{OH})_2$ and protects the concrete from efflorescence, sulphate attack and chloride attack. An alternative to cement for rural housing was discussed by Deepa Nair G. et.al [10] where they presented that about 90-95% of reactive silica was present in the RHA which was responsible for the pozzolanic behaviour of the rice husk ash. Minimization of environmental problems using rice-husk ash in concrete was discussed by Rawaid Khan et.al [11] and they concluded that concrete mixture containing 25% RHA as a replacement of OPC resulted in same strength as the concrete containing 100% OPC. The effect of silica fume on carbon nanotubes based cement composite was carried out by K.M.Mini et.al [12]

2. Experimental programme

The present investigation focuses on assessment of the suitability of Rice husk ash a cementitious material by conducting various physical and chemical analysis and hence to understand the influence of RHA on concrete properties (fresh state and hardened state). It was also proposed to determine the optimum level for replacement of RHA to attain maximum compressive strength and to understand the application of RHA in concrete beams.

2.1 Materials

Ordinary Portland Cement (OPC) of 43 Grade was used to conduct the experimental work. The chemical analysis of the cement was performed to get the composition and the results are presented in Table 1.

Table 1. Chemical composition of cement.

Chemical Composition	Concentration
Lime saturation	0.9
Alumina modulus	1.23
Insoluble residue (%)	0.25
Magnesia	1
Sulphuric anhydride (SO_3) (%)	1.5
Loss on ignition (%)	0.8
Alkali	-
Chloride (%)	0.002
Humidity (%)	65±5

River sand, locally available and confirming to Zone II specification with respect to IS 383-1970 [13] was taken as fine aggregate and crushed stones of 20 mm nominal size was taken as coarse aggregate. To examine the suitability of rice husk ash as a replacement for cement, the various chemical and physical properties were carried out. These properties of RHA were compared with standard cement properties for assessing the correctness of RHA as a supplementary cementitious material.

Chemical analysis of Rice Husk Ash (RHA) sample was done at NRDCS (Natural Resources Development Co-operative Society Ltd.), Himayatnagar, Hyderabad. Two samples of Rice Husk Ash were taken for analysis and the one which contained more silica was selected for the experimental investigation. Table 2 reports the results of chemical analysis of sample 1 and sample 2.

Table 2. Chemical analysis of RHA

Chemical Composition	Concentration (Sample 1) Source: S.S Industrial Systems, Hyderabad	Concentration (Sample 2) Source: Vinayaka Agencies, Hyderabad
Silicon dioxide (SiO ₂)	79.84	73.68
Aluminium oxide (Al ₂ O ₃)	0.14	0.68
Ferric oxide (Fe ₂ O ₃)	1.16	0.93
Calcium oxide (CaO)	0.55	1.30
Magnesium oxide (MgO)	0.19	0.35
Sodium oxide (Na ₂ O)	0.08	0.12
Potassium oxide (K ₂ O)	2.90	2.37
Sulphur trioxide (SO ₃)	-	-
Carbon (C)	-	7.75

From the investigation it was found that the sample 1 contains more silica content and hence was used in the present investigation.

Various properties of rice husk ash like specific gravity, bulk density, fineness and pH level were determined and compared with that of the cement as shown in Table 3.

Table 3. Comparison of physical properties

Property	Rice Husk Ash	Cement
Specific Gravity	1.95	3.15
Bulk density	530 kg/m ³	1440 kg/m ³
Fineness	13%	2%

From Table 3 it was found that specific gravity of Rice Husk Ash was very less when compared to the specific gravity of cement. It was also noted that bulk density of Rice Husk Ash was less when compared to that of the cement. Because of low bulk density the volume occupied for a given mass was more and hence the RHA fills the pores in concrete making it impermeable. The fineness,

expressed as the percentage of sample retained after passing through 90 μ sieve was 13% where as the standard fineness of cement is 2% and hence the fineness of RHA was under acceptable limits. So, it can be used as supplementary cementitious material.

The pH meter gave the direct pH value of the Rice Husk Ash and was found out to be,

pH after stirring = 7.31

pH after 1 day = 7.19

pH after 5 days = 6.89

pH after 30 days = 6.27

It was noted that as the number of days increases, pH of Rice Husk Ash decreases. This shows that the alkalinity was decreasing and hence it can be inferred that the addition of Rice Husk Ash does not make the concrete alkaline in nature.

2.2 Concrete mixtures

The procedure for selection of suitable ingredients of concrete and determination of their relative amounts with the purpose of producing a concrete of the necessary strength, durability, and workability is termed as the concrete mix design. Mix ratio of 1: 1.64: 3.41 for water binder ratio of 0.55 was taken in the present investigation. Table 4 represents mix proportions of concrete for varying RHA replacements by weight of cement. The control concrete without RHA was also fabricated along with above mixes.

Table 4. Mix proportions of concrete for varying RHA replacements

Replacement percentage of RHA	Cement in kg/m^3	Rice Husk Ash in kg/m^3	Fine Aggregate in kg/m^3	Coarse Aggregate in kg/m^3	Water in kg/m^3
0 %	348.36	0	572.74	1189.5	191.60
5 %	330.94	17.42	572.74	1189.5	191.60
10 %	313.52	34.83	572.74	1189.5	191.60
15 %	296.11	52.2	572.74	1189.5	191.60
20 %	278.7	69.6	572.74	1189.5	191.60

2.3 Testing of Specimens

Various experiments to find the fresh state and hardened properties of cement mortar and concrete at varying percentages of RHA were conducted in the present investigation. The RHA percentages correspond to 0%, 5%, 10%, 15% and 20% by weight of cement. Various experiments like consistency test, initial and final setting time were carried out on cement mortar in order to find out the water content necessary to produce a binder (cement + %RHA) paste with standard consistency as specified by the IS: 4031 (Part 4) – 1988[15] and IS:4031 (Part 5)-1988 [15] . Table 5 gives the values of normal consistency, initial and final setting time of cement mortar for varying percentages of RHA.

Table 5. Cement Properties – Consistency & Setting Time

% of RHA	Consistency in %	Initial setting time (min)	Final setting time (min)
0	41	55	141
5	44	41	136
10	46	32	130
15	47	29	125
20	51	24	118

Fresh state properties of the mixture were assessed by conducting workability tests, slump test, Vee-Bee consistometer test and compaction factor test using IS: 1199-1959[17] as reference. Hardened properties like compressive strength, split tensile strength and flexural strength were carried out to assess the strength parameters related to varying percentages of RHA. The compressive strength test was performed on standard cubes of size 150 mm using 2000 kN compression testing machine in reference with IS: 516 -1959 [17]. The compressive strength was then found for 7, 14 and 28 days respectively. The Split Tensile Strength (STS) of concrete at 7 and 28 days was performed on cylindrical specimen of 150 mm diameter, 300 mm height using 2000 kN compression testing machine. The Flexural Tensile Strength (FTS) was performed on beams of size 100×100×500mm after 28 days curing. The test was done in accordance with IS: 516-1959 using 400 kN universal testing machine. The water absorption test was also conducted and the increase in weight with respect to the percentage of the original weight was expressed as its absorption (in percent). Three specimens were used for carrying out every test and average of three results was reported.

3. Results and discussion

3.1 Fresh concrete properties

Workability of concrete assesses the behaviour of fresh concrete from mixing upto compaction. The terms mix-ability, transportability, mouldability and compactability collectively represent workability. Various tests were performed to measure workability of concrete and the effects of RHA on workability properties of concrete were studied.

The workability values in terms of Slump (mm), Vee –Bee Degrees (sec.) and compaction factor for varying RHA percentage of concrete mix at a temperature of 32⁰ C are given in Table 6.

Table 6. Fresh concrete properties

% of RHA	Slump Values(mm)	Vee-Bee Degrees (seconds)	Compaction Factor
0	65	3	0.882
5	55	6	0.866
10	32	9	0.782
15	14	12	0.661
20	6	19	0.601

The results of slump test to assess the workability of fresh concrete indicates that incorporation of RHA in concrete leads to a decrease in slump value, which depends on the RHA content. This reduction in slump was due to the absorption of some quantity of mixing water by RHA particles. Because of the large surface area of RHA, more water molecules were attracted towards the surface of these particles. Thus, the quantity of the free water available for the concrete mix which helps in improving the fluidity of the mixture was decreased and there was an increase in the viscosity of the concrete mix. This in turn reduces the workability of the concrete and the effect was the same for other two tests also.

3.2 Compressive strength

The improvement of compressive strength from a period of 7 days to 28 days for mixes with varying percentages of RHA is presented in Fig. 1. The percentage increase in compressive strength from control specimen to specimens with varying percentages of RHA is reported in Table 7. The table indicates that the 28 days strength increases from 27 MPa to 29.3 MPa with incorporation of 10% RHA. This 8.51% enhancement of compressive strength of concrete with RHA was attributed to the increase in pozzolanic action when RHA was added in concrete. However, for other variations in RHA, there was a reduction in compressive strength of concrete after a curing period of 28 days. When the percentage replacement of Rice husk ash was increased, the compressive strength of Rice husk ash concrete was also found to increase slowly, up to nearly 10% replacement and then decreased.

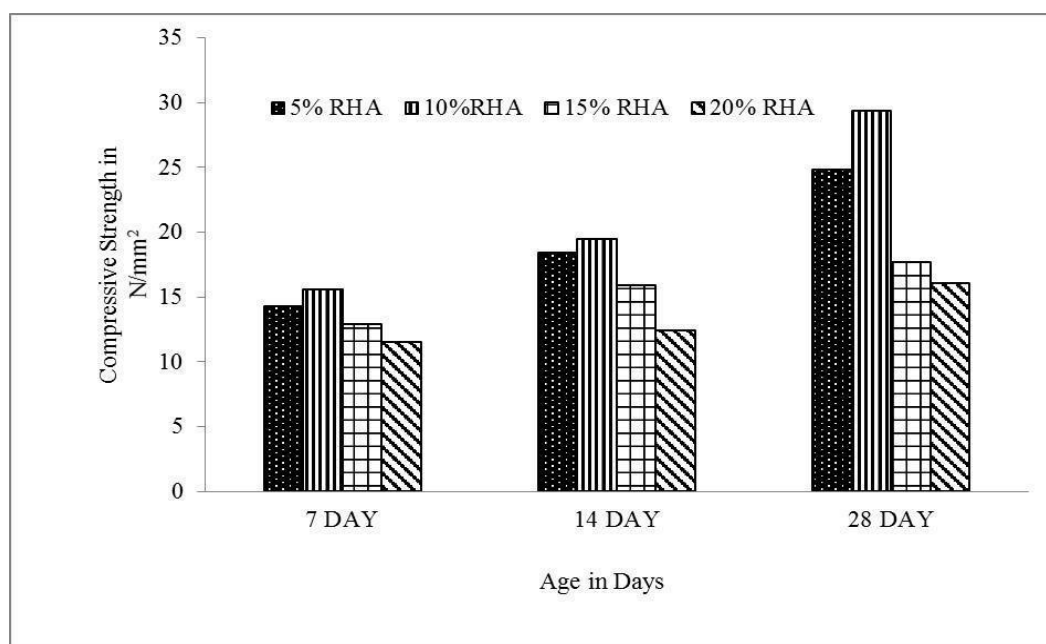


Figure 1. Compressive strength of concrete for varying percentage of RHA.

Table 7. Compressive strength percentage variation with respect to 0% RHA

% of RHA	Compressive strength for 28 days curing period	Percentage change from 0% RHA
0	27	-
5	24.8	-8.15
10	29.3	-8.51
15	17.6	-34.81
20	16.03	-40.62

3.3 Split tensile strength

Fig. 2 shows the variation of split tensile strength with respect to the percentage of RHA. Table 8 reports the split tensile strength percentage variation with respect to 0% RHA for different RHA replacements. Increase in the split tensile strength of concrete can be seen from 2.28 MPa to 2.52 MPa as the percentage of RHA increases from zero to 10%. The enhancement of split tensile strength may be due to the strengthening of Interfacial Transition Zone (ITZ) by the silica content present in RHA. The individual ingredients of concrete such as cement, fine and coarse aggregate have a higher tensile strength when tested independently. However, when they are mixed to form concrete, the tensile strength was found to be lesser when compared to the individual strength. This may be due to the fact that even though ITZ is one of the weakest link in concrete, the existence of silica content in RHA makes a stronger and denser ITZ when compared to the normal concrete as it helps in reducing the voids present in ITZ, but with 15% and 20% RHA the strength was found to be decreasing. When the percentage replacement of Rice husk ash was increased, the split tensile strength of Rice husk ash concrete was also found to be increasing slowly, up to nearly 10% replacement and then it decreased. Graph between split tensile strength and curing period for varying percentage of RHA is shown in figure 2.

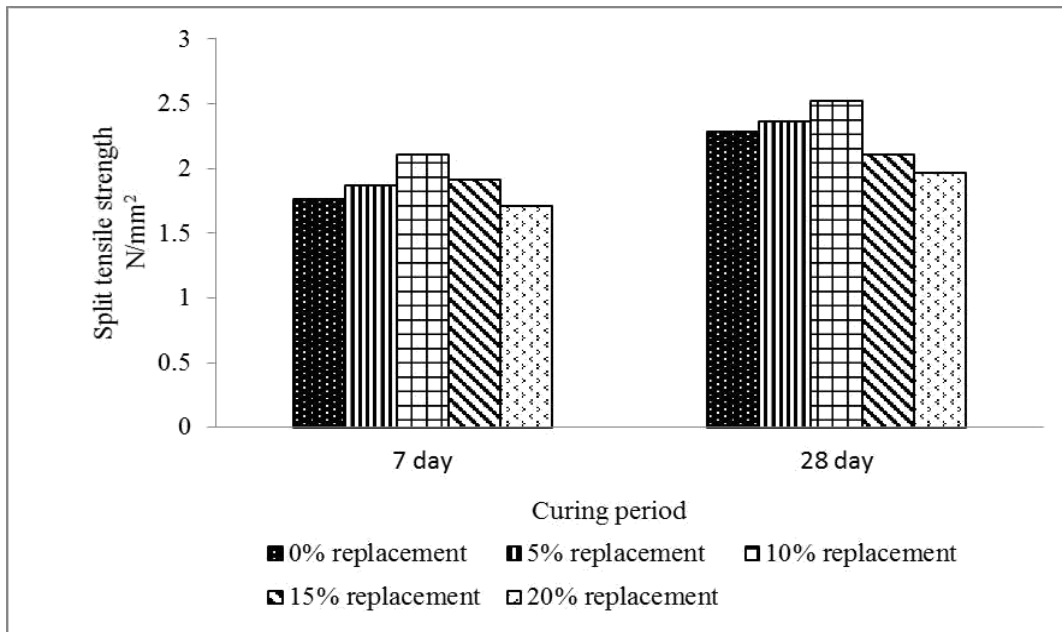


Figure 2. Variation in Split Tensile strength for varying percentage of RHA

Table 8. Split tensile strength percentage variation with respect to 0% RHA for different RHA replacements

Concrete mix type	Split tensile strength for 28 days in N/mm^2	Split tensile strength percentage change from 0% RHA
For 0% replacement	2.28	-
For 5% replacement	2.36	3.5%
For 10% replacement	2.52	10.5%
For 15% replacement	2.11	-7.45%
For 20% replacement	1.97	-13.59%

3.4 Water absorption Test

In this test a dried specimen of known weight was immersed in water for a specified period of time. After that period, the specimen was weighed again and the increase in weight with respect to the percentage of the original weight was expressed as its water absorption (in percent). Percentage values of water absorbed for different RHA percentage are reported in Table 9.

Table 9. Percentage of water absorbed for varying percentage of RHA

RHA percentage	Water Absorbed
5%	1.28%
10%	1.49%
15%	1.64%
20%	1.86%

From the Table 9 it was found that water absorption increases as the percentage of RHA increased. This may be due to the fact that as RHA is more porous water fills the pores which increase the water absorption rate.

3.5 Flexural strength

The change in flexural strength with respect to different percentages of RHA is represented in Fig. 3, which shows that maximum Flexural Tensile Strength (FTS) was reached corresponding to 10% addition of RHA. The improvement of 20% in FTS due to 10% addition of RHA was because of the increase in strength of concrete with the addition of RHA. The interfacial transition zone of concrete becomes stronger because of the pozzolanic products given out by RHA that helps in improving the bonding between cement mortar and aggregate. However, the FTS of concrete reduces for other percentages of RHA. Flexural strength percentage variation with respect to 0% RHA for different RHA replacements is reported in Table 10. As the percentage replacement of Rice husk ash increases, there was also a gradual increase in the flexural strength of Rice husk ash concrete up to nearly 10% replacement and then it decreases.

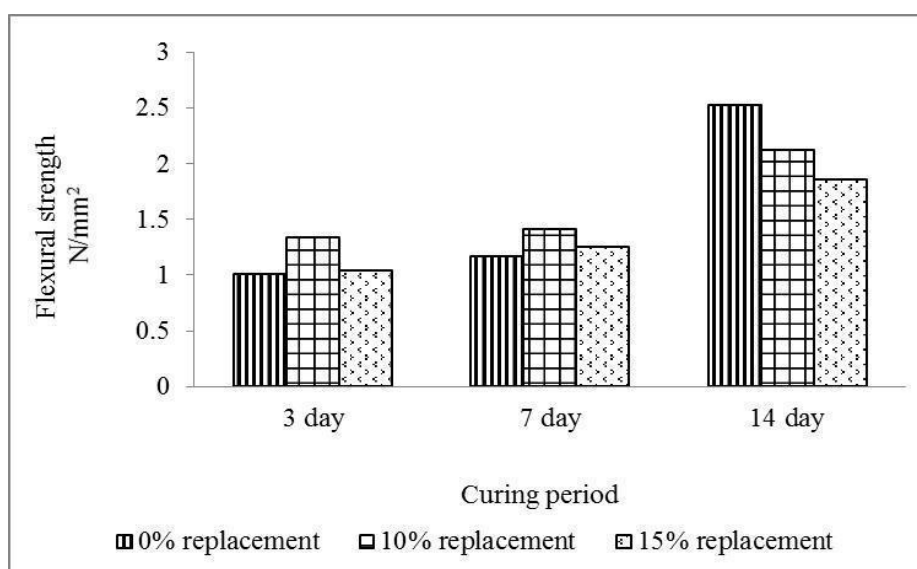
**Figure 3.** Flexural strength vs curing period for varying percentage of RHA.

Table 10. Flexural strength percentage variation with respect to 0% RHA for different RHA replacements

%RHA	Flexural strength for 28 days in N/mm ²	Percentage change from 0% RHA
For 0% replacement	2.11	-
For 10% replacement	2.53	19.9%
For 15% replacement	1.94	-8.06%

4. Conclusions

The present work explores the suitability of using Rice husk ash as a replacement of cement partially. The suitability of rice husk ash as a cementitious material was assessed by conducting the physio-chemical analysis of the ingredients and the influence of RHA on concrete properties (fresh state and hardened state). From the chemical analysis conducted on RHA it was found that it contains nearly 80% silica. To assess the fresh stage properties, the workability values in terms of Slump (mm), Vee – Bee Degrees (sec.) and compaction factor for varying RHA percentage of concrete mix at a temperature of 32° C were carried out and the results were analysed. Hardened properties like compressive strength, split tensile strength and flexural strength properties were evaluated. To check the efficiency of sample in terms of water absorption, a water absorption study was conducted. From the experimental investigation it was found that optimum replacement of Rice Husk ash in cement was near to 10% in terms of workability and strength. The usage of Rice husk ash in concrete as a replacement for cement can decrease the emission of green-house gases to a larger extent which automatically increases the possibility for gaining more number of carbon credits.

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