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EFFECT OF PARTIAL REPLACEMENT OF CEMENT BY RICE HUSK ASH IN FIBRE REINFORCED CONCRETE'S MECHANICAL AND TOUGHNESS PROPERTIES

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ABSTRACT

In present day constructions, usage of High Performance Concrete (HPC) is predominant. HPC can be a fibre-reinforced, super plasticized cement mixture with a very low water-cement ratio. Though it has superior mechanical and durability property, it contains large amount of cement resulting in high cost of powders and an irreparable snag when sustainable development is considered. In this respect, using mineral admixtures can be an attractive alternative, especially when an agro by-product can act as one. Recent studies have shown that, Rice Husk Ash (RHA) which is an agro waste fulfils the physical characteristics and chemical composition of mineral admixtures. In this paper the effect of partial replacement of cement by rice husk ash in fibre reinforced concrete's mechanical and toughness properties is studied. Fibre reinforced concrete with different replacement levels of RHA was prepared and these specimens were subjected to compression test, flexural strength test, split tensile strength test and impact test. The specimens with 5% replacement level of RHA gave maximum strength for all the tests.

KEYWORDS: Compressive Strength, Fibre Reinforced Concrete, Flexural Strength, Impact Resistance, Rice Husk Ash, Splitting Tensile Strength

INTRODUCTION

Fibre Reinforced Concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres each of which lend varying properties to the concrete. In addition, the character of fibre reinforced concrete changes with varying fibre materials, geometries, distribution, orientation, and densities. The concept of using fibres as reinforcement is not new. Historically, horsehair was used in mortar and straw in mud bricks. In the 1900s, asbestos fibres were used in concrete. By the 1960s, steel, glass and synthetic fibres such as polypropylene were used in concrete. Research into new fibre-reinforced concretes continues today. Fibres are usually used in concrete to control cracking due to plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibres produce greater impact, abrasion, and shatter resistance in concrete. In common practice, the amount of fibres added to the concrete mixture depends on the properties of the cement based matrix and performance objectives. Typically, lower amount of fibres are used to control shrinkage cracking and their prime application area are slabs and pavements, which have large exposed surfaces that are highly susceptible to shrinkage cracking.

Recent work carried out on the formulation and manufacture of concrete has led to the development of high performance concrete, which is considered to be one of the latest advances in concrete technology. In general, HPC can be a fibre-reinforced, super plasticized cement mixture with a very low water-cement ratio. Though it has superior mechanical and durability property, it usually contains large amount of cement resulting in high cost of powders and an irreparable snag when sustainable development is considered. The production of cement increases the content of CO_2, which have adverse impacts on global warming. In this respect, using the mineral admixtures can be an attractive alternative. For these reasons, it gives a motivation for searching materials which can be used as mineral admixtures. Recent studies have shown that rice husk ash which is an agro waste fulfils the physical characteristics and chemical composition of mineral admixtures. Rice husk ash is very promising in terms of technical, economical, and environmental feasibility. Rice husk constitutes about one fifth of the 690 million metric tons of rice paddy produced annually in the world. When completely incinerating the husk in appropriate conditions, the residue, RHA, contains 90-96% silica in an amorphous form. Rice husk ash is classified in the category of highly active pozzolans. However, RHA has a very high specific surface area which is attributed to its porous structure. Therefore, the difference in particle characteristics will be expected to produce different effects on the hydration and microstructure development of cement paste.

From recent studies we can see that the particle size of RHA and addition of fibres have effect on the strength of concrete. *Givi et al.* [1] studied on the effects of particle size of rice husk ash on strength, water permeability and workability of concrete with partial replacement of cement with rice husk ash. It is concluded that partial replacement of cement with rice husk ash improves the compressive strength and workability of concrete and decreases its water permeability. *Kang et al.* [2] studied on the tensile fracture properties of Ultra High Performance Fibre Reinforced Concrete (UHPFRC) considering the effects of the fibre content. From the bending tests, it was found that the flexural tensile strength of UHPFRC linearly increases with increasing fibre volume ratio. Also from the parametric study, it is found that the strength parameters are linearly dependent on fibre content. *Kishore et al.* [3] investigated the mechanical properties of high strength concrete with different replacement levels of ordinary Portland cement by rice husk ash. The strength effect of high strength concrete of various amounts of replacement of cement with rice husk ash on M40 and M50 grade concrete were compared with that of the high strength concrete without rice husk ash. The results of the mechanical properties of the rice husk ash at 28 days have shown that the optimum replacement of rice husk ash found to be 10% in both the grades of the concrete.*Kim et al.* [4] studied the flexural performance of four Hybrid (H-) UHPFRCs with different macro fibres. Four types of macro high strength steel fibres investigated are Long Smooth (LS-), Hooked (two types HA- and HB-) and Twisted (T-) fibre. They observed that H-UHPFRCs show significantly better flexural performance in both deflection capacity and energy absorption capacity compared. *Antiohos et al.* [5] investigated the effectiveness of rice husk ash in cement and concrete as a function of reactive silica and fineness. From the tests, it was revealed that the higher being the fineness the more positive is the effect of RHA inclusion in the mix. *Abbas et al.* [7] investigated on the influence of the steel fibre length and dosage on the mechanical and durability performance of ultra high performance concrete. The results showed the compressive strength of UHPC slightly increased with steel fibre addition, while the fibre length had insignificant effect on compressive strength. Higher fibre dosage improved durability properties.

In this paper the effect of partial replacement of cement by RHA on the mechanical and toughness properties of fibre reinforced concrete is studied. The fibre used here is hooked end steel fibre. Various tests were performed to know the behaviour of RHA concrete and these includes compressive strength test, split tensile strength test, flexural strength test, shear strength test, modulus of elasticity and impact resistance test.

MATERIALS AND METHODS

Materials

Ordinary Portland cement (Coromandel King 53 grade)of specific gravity 3.14 is used in this study. Manufacturer's sand is used as fine aggregate. The particle size distribution curve of fine aggregate is shown in Figure 1.The fine aggregate belongs to Zone II [13]. The specific gravity and fineness modulus of fine aggregate are 2.4 and 3.79 respectively. Coarse aggregates used were blended aggregates of maximum sizes 12 mm and 6 mm. The specific gravity of coarse aggregate is 2.7. Hooked end steel fibre of diameter 0.5 mm and length 30 mm is used for this study. As per the manufactures data the range of ultimate tensile strength on tension test is above 1100 MPa for diameters ranging from 0.45-1mm. The density of steel fibre is 7850 kg/m^3. A poly carboxylic ether based super plasticizer is used. Rice husk ash is used as the mineral admixture. The specific gravity of RHA was found to be 2.05 and its chemical composition is listed in Table 1.

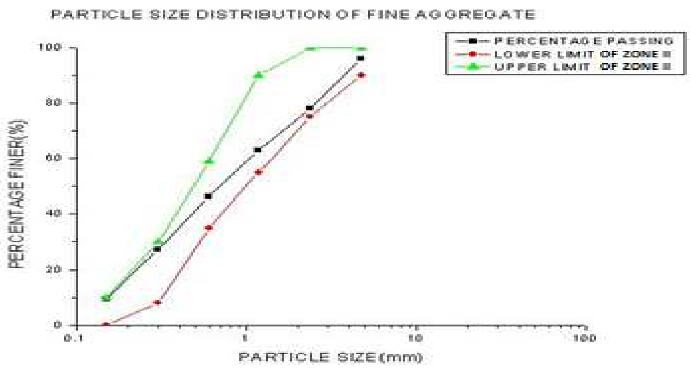


Figure 1: Particle Size Distribution Curve of Fine Aggregate

Table 1: Chemical Composition of RHA (As per Manufactures Data)

Item	Chemical Content
Silicon dioxide (SiO_2)	79.84
Aluminium oxide (Al_2O_3)	0.14
Ferric oxide (Fe_2O_3)	1.16
Calcium oxide (CaO)	0.55
Magnesium oxide (MgO)	0.19
Sodium oxide (Na_2O)	0.08
Potassium oxide (K_2O)	2.90
Phosphorous oxide (P_2O_5)	0.8
Titanium oxide (TiO_2)	0.01
Manganese oxide (MnO)	0.07
Carbon (C)	7.75
Loss on ignition (LOI)	14.26

Experimental Methodology

The experimental program was designed to determine the mechanical and the toughness properties of the fibre reinforced concrete with different replacement levels of ordinary Portland cement by RHA. M40 grade concrete is used. In the first series, the specimens were cast with different replacement levels of cement by RHA (0%, 5%, 10%, 15% and 20%). The optimum percentage of replacement by RHA was found out by performing compression test. Similarly, the optimum dosage of steel fibre was obtained by varying the percentage of steel fibres (0%, 0.25%, 0.5%, 0.75% and 1% of concrete). Then in the second stage specimens were cast using the mix proportions corresponding to the optimum dosage of steel fibres. The RHA replacement level was varied in it and the hardened properties of each mixes were investigated.

Mix Design and Optimum Mix

The mix design is carried out as per Indian Standards [10, 14]. The quantities required for $1m^3$ of concrete is calculated and is tabulated in Table 2(f_a and c_a denotes fine and coarse aggregate quantities respectively).

Table 2: Quantities Required for $1m^3$ of Concrete

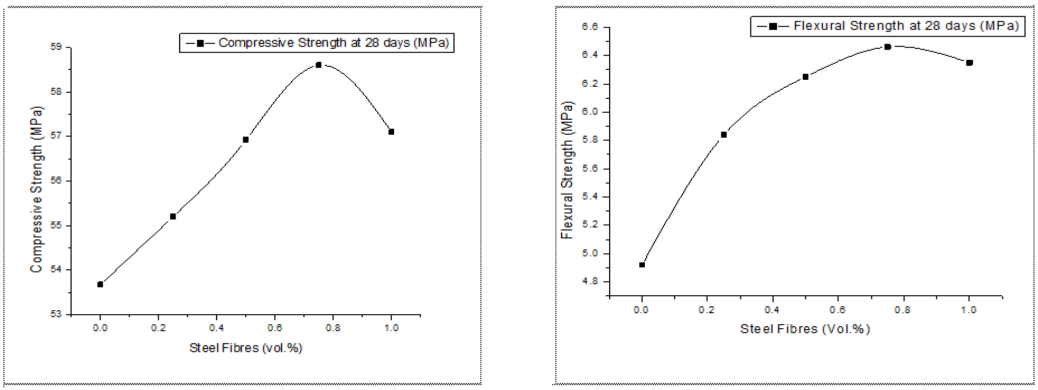
w/c	Water (kg)	Cement (kg)	f_a (kg)	c_a (kg)
0.40	167.1	417.6	770.6	1055.4

Optimum Dosage of Steel Fibres

To find out the optimum dosage of steel fibres, concrete cubes of size 150X150X150 mm and beams of size 150X150x700 mm is cast by varying the percentage of steel fibres as 0%, 0.25%, 0.5%, 0.75% and 1% of volume of concrete. The mix proportions for different percentage of steel fibres are shown in Table 3. Twenty eight days compressive strength and flexural strength are determined. The compressive strength test result and the flexural strength test results are shown in Figure 2 (a) and (b) respectively. From the test results it is observed that adding 0.75% of steel fibres gives maximum compressive and flexural strength.

Table 3: Quantities Required for $1m^3$ of Concrete (with Steel Fibre)

Steel Fibre (Vol. %)	Water (kg)	Cement (kg)	Steel Fibre (kg)	f_a (kg)	c_a (kg)
0	167.1	417.6	0	770.6	1055.4
0.25	166.68	416.56	19.63	768.68	1052.77
0.50	166.27	415.52	39.25	766.76	1050.15
0.75	165.86	414.49	58.88	764.87	1047.55
1.00	165.45	413.47	78.5	762.97	1044.92



(a) (b)

Figure 2: (a) Compressive Strength (b) Flexural Strength of Concrete with Steel Fibres

Optimum Replacement Level of Rice Husk Ash

The mix proportions for different replacement level of cement by RHA are shown in Table 4. Concrete cubes of size 150mm X 150mm X 150mm is cast and compression test is performed on these specimens after 28 days and 56 days, in order to obtain the optimum percentage of replacement of cement by RHA. The test results are shown in Figure 3. From the test results it is observed that 5% replacement of cement by RHA gives maximum compressive strength and it is about 90% of that of the mix without RHA. When we compare the 28 days compressive strength and 56 days compressive strength, we can observe that RHA concrete shows better increase in compressive strength compared to the concrete without RHA.

Table 4: Quantities Required for 1m^3 of RHA Concrete

Percentage Replacement of Cement by RHA (%)	Water (kg)	Cement (kg)	RHA (kg)	f_a (kg)	c_a (kg)
0	167.1	417.6	0	770.6	1055.4
5	167.1	396.72	20.88	770.6	1055.4
10	167.1	375.84	41.76	770.6	1055.4
15	167.1	354.96	62.64	770.6	1055.4
20	167.1	334.08	83.52	770.6	1055.4

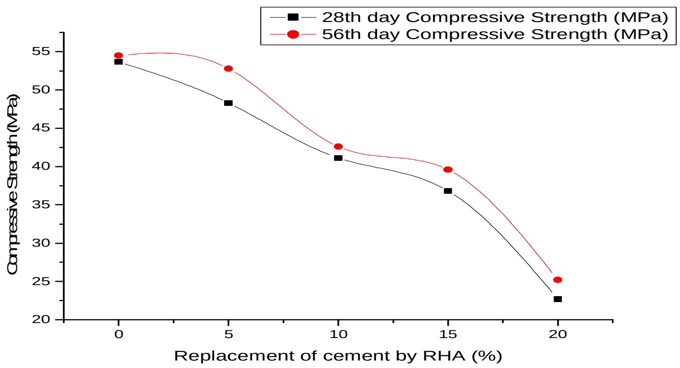


Figure 3: Compressive Strength of RHA Concrete at 28 Days and 56 Days

After obtaining the optimum replacement level of cement by RHA and the optimum dosage of steel fibre in the M40 grade concrete discretely (which were 5% of cement and 0.75% of volume of concrete, respectively), for further study, the specimens were prepared using the mix proportions corresponding to the optimum dosage of steel fibres and the RHA replacement level in it was varied proportionally from the optimum replacement level obtained, by +2.5% and -2.5%. Therefore, the different replacement levels of RHA provided for the specimens are 2.5%, 5% and 7.5% and these specimens are designated as $R_{2.5}S_{0.75}$, $R_5S_{0.75}$ and $R_{7.5}S_{0.75}$. The mix without RHA and with 0.75% vol. of steel fibre ($S_{0.75}$) is taken as the control mix. The mix proportions are tabulated in Table 5.

Table 5: Quantities Required for 1m^{3}of RHA Concrete (with Steel Fibre)

Designation	Steel Fibre (Vol. %)	Percentage Replacement of Cement by RHA (%)	Water (kg)	Cement (kg)	RHA (kg)	Steel Fibre (kg)	f_a (kg)	c_a (kg)
$S_{0.75}$	0.75	0	165.86	414.49	0	58.88	764.87	1047.55
$R_{2.5}S_{0.75}$	0.75	2.5	165.86	404.13	10.36	58.88	764.87	1047.55
$R_5S_{0.75}$	0.75	5	165.86	393.76	20.73	58.88	764.87	1047.55
$R_{7.5}S_{0.75}$	0.75	7.5	165.86	383.40	31.09	58.88	764.87	1047.55

Compressive Strength Test

The compression test is carried out on cubical specimen of size 150 X 150 X 150 mm. The specimens are tested by after 28 days and 56 days of curing. Load is applied gradually at the rate of 140 kg/cm^2 per minute till the specimens fails.

Flexural Strength Test

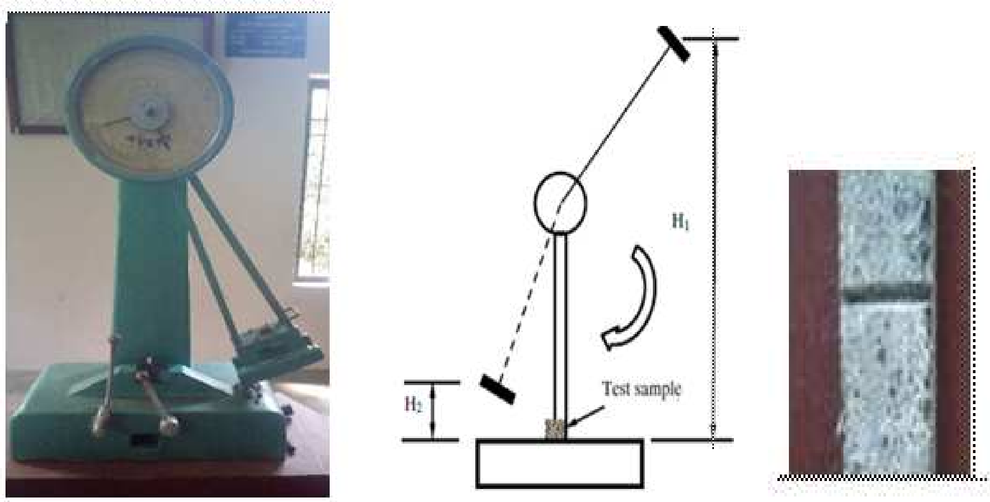
Beams of size 150mm x 150mm x 700 mm was used for conducting the experiments. The beams are subjected to symmetrical two point loading until failure occurs and the modulus of rupture was calculated.

Split Tensile Strength Test

It is a standard test to determine the tensile strength of concrete in an indirect way. Cylinder of 150 mm diameter and 300 mm height is used as specimen. The load is applied until failure of the cylinder, along the vertical diameter.

Impact Test

Impact test is used to determine the toughness of the concrete. In this study charpy impact test is employed to evaluate the impact resistance capacity of concrete. The charpy impact device is shown in Figure 4(a) and its working scheme in Figure 4(b). Specimens of size 12.7mm X 12.7mm X 50.8mm were used for the test. The specimen is provided with a U- notch in the middle as shown in Figure 4(c). In this experiment, the specimen is subjected to hammer caused by a pendulum of known weight kept at a known height H. The pendulum then swings through the specimen after hitting and breaking to a height H_2.



(a) (b) (c)

Figure 4: (a) Charpy Impact Test Device Used in This Study (b) Its Working Scheme (c) U Notch Provided for the Specimen

RESULTS AND DISCUSSIONS

Compressive Strength Test

The compressive strength test results are presented Figure 4. From the results obtained it can be seen that $R_5S_{0.75}$ mix shows maximum compressive strength compared to the other two mixes. When the RHA replacement level is increased more than 5% the compressive strength decreases. The compressive strength of $R_5S_{0.75}$ after 28 days of curing is about 87.30% of that of the control mix ($S_{0.75}$). The reduction in strength of $R_5S_{0.75}$ compared to the control mix may be due to slow pozzolanic reaction of RHA.

Flexural Strength Test

The flexural strength test results are shown in Figure 5. $R_5S_{0.75}$ mix gave the maximum flexural strength. It shows 89.94% of flexural strength of control mix at 28 days test.

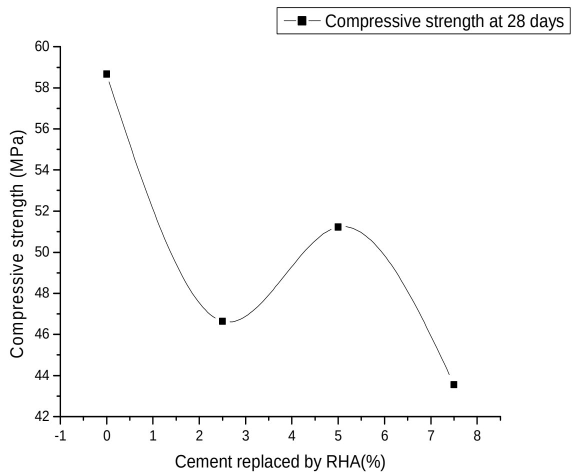


Figure 4: Compressive Strength of RHA Concrete (with 0.75 vol. % fibres) at 28 Days

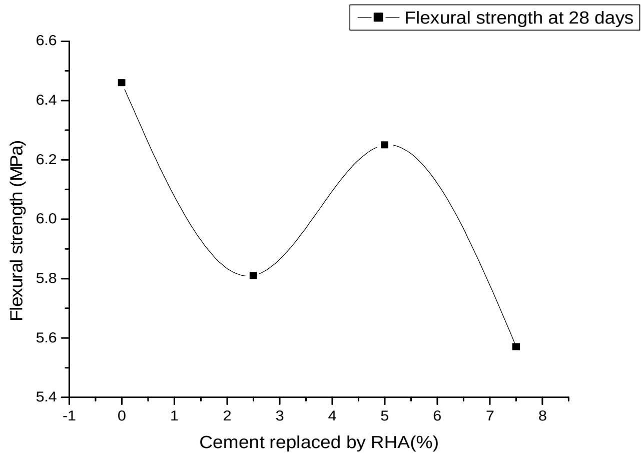


Figure 5: Flexural Strength of RHA Concrete (with 0.75 vol. % fibres) at 28 Days

Splitting Tensile Strength Test

Figure 6 shows the splitting tensile strength results. From Figure we can see that the split tensile strength of the mix with 5% replacement level of cement by RHA is 98.05% of that of the control mix.

Impact Test

Figure 6depicts the impact test results of concrete with fibre as in the case of compression, flexure and split tensile strength, $R_5S_{0.75}$ mix showed maximum impact resistance compared to the other RHA mixes. From figure we can see that the energy absorbed by $R_5S_{0.75}$ mix is 92.78% of that of $S_{0.75}$. Fibre reinforced concrete shows greater impact resistance compared to plain concrete. This is because the energy absorption of fibre reinforced concrete specimen mainly includes two parts i.e.; the energy used to break the concrete matrix and the energy used to pull out the fibres embedded in the broken crossections.

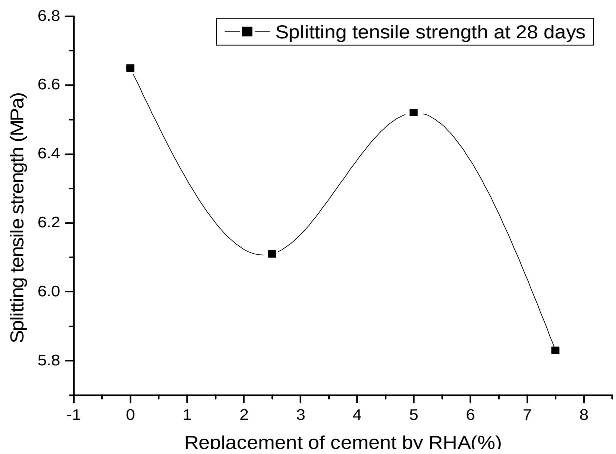


Figure 5: Splitting Tensile Strength of RHA Concrete (with 0.75 vol. % fibres) at 28 Days

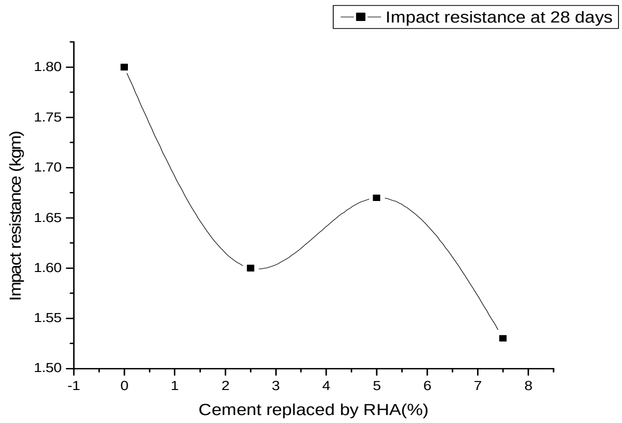


Figure 6: Impact Resistance of RHA Concrete (with 0.75 vol. % Fibres) at 28 Days

CONCLUSIONS

- Concrete mix with 5% replacement level of RHA gave maximum compressive strength, flexural strength, split tensile strength and impact resistance.
- The RHA concrete showed low strength compared to concrete without RHA. This may be due to slow pozzolanic reaction.
- The rate of increase in strength with age was good for RHA concrete.
- The results of mechanical and toughness properties of RHA concrete have shown quite encouraging and interesting results.

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