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Corrosion performance of rice husk ash blended concrete

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Abstract

Rice husk ash is one of the promising pozzolanic materials that can be blended with Portland cement for the production of durable concrete and at the same time it is a value added product. Addition of rice husk ash to Portland cement not only improves the early strength of concrete, but also forms a calcium silicate hydrate (CSH) gel around the cement particles which is highly dense and less porous. This may increase the strength of concrete against cracking. So far a systematic and detailed investigations on the corrosion performance of rice husk ash blended concrete is very scarce. Therefore, in the present investigation, a realistic approach has been made using different techniques such as compressive strength, bond strength, split tensile strength etc. Corrosion performance was evaluated using, open circuit potential measurements, rapid chloride ion permeation test and impressed voltage test and the results were discussed.

Keywords: Rice husk ash; Strength; Corrosion; Porosity

1. Introduction

Rice husk ash (RHA) has been used as a highly reactive pozzolanic material to improve the microstructure of the interfacial transition zone (ITZ) between the cement paste and the aggregate in high-performance concrete. Mechanical experiments of RHA blended Portland cement concretes revealed that in addition to the pozzolanic reactivity of RHA (chemical aspect), the particle grading (physical aspect) of cement and RHA mixtures also exerted significant influences on the blending efficiency. The relative strength increase (relative to the concrete made with plain cement, expressed in %) is higher for coarser cement [1]. Results indicated that such a pozzolana can be produced with varying pozzolanic activity index depending on the degree of grinding and the burning temperature. The effect of rice husk ash content as partial replacement of cement on compressive strength and volume changes of different mixes is investigated. Test results showed that up to 40% replacement could be made with no significant change in compressive strength compared with the control mix [2].

It is also reported that the microstructure of the cement paste can be significantly improved by adding pozzolanic materials such as, fly ash, silica fume, metakaolin and rice husk ash (RHA). Rice husk ash is a highly reactive pozzolanic material produced by controlling burning of rice husk ash. The utilization of rice husk ash as a pozzolanic material in cement and concrete provides several advantages, such as improved strength and durability properties, reduced materials cost due to cement savings and environmental benefits related to the disposal of waste materials and to reduced carbon di oxide emissions. Reactivity of RHA is attributed to its high content of amorphous silica, and to its very large surface area governed by the porous structure of the particles [3–6]. Generally, reactivity is also favoured by increasing fineness of the pozzolanic material [7–9]. However, Mehta [10] has reported that grinding of RHA to a high degree of fineness should be avoided, since

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it derives its pozzolanic activity mainly from the internal surface area of the particles. By blending rice husk ash with courser cement, higher packing can be expected, leading to improved behaviour of blended systems [11,12].

In the present investigation, rice husk ash was blended with ordinary Portland cement at various percentages by simple replacement method and a realistic assessment of the corrosion resistant properties has been made in addition to the mechanical properties and the results were compared with conventional Portland cement concrete.

2. Experimental details

2.1. Materials used

Ordinary Portland cement (OPC):	Conforming to IS 8112-1989 was used for the investigation is given in Table 1.
Graded fine aggregates:	Local clean river sand (fineness modulus of medium sand equal to 2.46) conforming to grading zone III of IS-383-1970 was used.
Graded coarse aggregates:	Locally available well graded aggregates of normal size greater than 4.75 mm and less than 12 mm.

3. Tests conducted

(a) Compression test,
(b) Split tensile test,
(c) Pull-out test,
(d) Effective porosity,
(e) Coefficient of water absorption,
(f) Rapid chloride ion penetration test (RCPT),
(g) Impressed voltage test and
(h) Open circuit potential measurement.

3.1. Compressive strength

Compressive strength test was carried out in concrete cubes of size 100 × 100 × 100 mm using 1:1.5:3.0 mix with W/C ratio of 0.53. Specimens with ordinary Portland cement concrete (control) and OPC replaced by rice husk ash at 5%, 10%, 15%, 20%, 25% and 30% replacement levels were cast. During moulding, the cubes were mechanically vibrated. After 24 h, the specimens were removed from the mould and subjected to water curing for 7, 14 and 28 days. After a specified period of curing, the specimens were tested for compressive strength using AIMIL compression testing machine of 2000 kN capacity at a rate of loading of 140 kN/min. The tests were carried out on triplicate specimens and the average compressive strength values were recorded.

3.2. Split tensile test

Split tensile test was carried out as per ASTM C496-90. Concrete cylinders of size 150 mm diameter and 300 mm height were cast using 1:1.50:3.0 mix with W/C ratio of 0.53. Specimens with OPC and OPC replaced by rice husk ash at 5%, 10%, 15%, 20%, 25% and 30% replacement levels were cast. During moulding, the cylinders were mechanically vibrated using a table vibrator. After 24 h, the specimens were removed from the mould and subjected to water curing for 7,14 and 28 days. After the specified curing period was over, the concrete cylinders were subjected to split tensile test by using universal testing machine. Tests were carried out on triplicate specimens and average split tensile strength values were recorded.

3.3. Pull-out test

Pull-out test was carried out as per IS 2770 – 1967 – Part-1. Cold twisted deformed bars of 12 mm diameter and 450 mm long were used for steel-concrete bond strength determination. The rod was placed centrally along with helical reinforcement provided in the centre of the concrete cube of size 100 × 100 × 100 mm using a concrete mix of 1:1.50:3.0 with W/C ratio equal to 0.53. Specimens with OPC and OPC replaced by rice husk ash at 5%, 10%, 15%, 20%, 25% and 30% replacement levels were cast. The bar is projected down for a distance of about 10 mm from the bottom face of the cube as cast and projected upward from the top up to 300 mm height in order to provide an adequate length to be gripped for application of load. During casting of concrete cubes, the moulds were mechanically vibrated. The cubes were removed from the mould after 24 h and then cured for 28 days with complete immersion in distilled water. After the curing period was over the steel-concrete bond strength was determined using Universal Testing Machine (Model: UTE-60) of capacity 60t. The bond strength was calculated from the load at which the slip was 0.25 mm. Tests were carried out in triplicate specimens and average bond strength values were obtained.

3.4. Effective porosity test

Water absorption test was carried out as per ASTM C642-97. For determination of effective porosity and coefficient of water absorption, discs of size 83 mm diameter and 50 mm thick were cast with and without rice husk ash at 5%, 10%, 15%, 20%, 25% and 30% replacement levels and cured for 28 days in distilled water. After the curing period was over the specimens were dried in an oven at 105 °C ± 5 °C for 48 h in order to evaporate the moisture content present in the concrete. The effective porosity and coefficient of water absorption are calculated as follows:

Table 1
Composition of OPC and rice husk ash (RHA) used for the investigation

Constituents	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	LOI	Others
OPC	63.90	22.00	5.60	4.00	1.70	2.30	—	—	1.10	0.20
RHA	0.53	92.95	0.31	0.26	0.55	—	2.06	0.08	1.97	0.12

$$\text{Effective porosity } (\%) = \frac{B-A}{V} \times 100$$

Where,

A mass of oven dried sample in air
B saturated mass of the surface dry sample in air after immersion
V bulk volume of the sample

3.5. Coefficient of water absorption

The Coefficient of water absorption test was carried out as per ASTM C642-97. The same specimens used for effective porosity was used for this study also. Coefficient of water absorption is a measure of water permeability and is calculated as follows:

Coefficient of water absorption $K_a(\text{m}^2/\text{sec}) = \left(\frac{Q}{A}\right)^2 \times \frac{1}{t}$

K_a Coefficient of water absorption
Q Quantity of water absorbed by the oven dried specimen in time t, t–60 min
A Total surface area of concrete through which water penetrates

3.6. Rapid chloride ion penetration test (RCPT)

This test was conducted as per ASTM C1202-94. Concrete disc of size 85 mm diameter and 50 mm thickness with and without rice husk ash were cast and allowed to cure for 28 days. After 28 days of curing the concrete specimens were subjected to RCPT test by impressing 60 V. Two halves of the specimen are sealed with PVC container of diameter 90 mm. One side of the container is filled with 3% NaCl solution (that side of the cell will be connected to the negative terminal of the power supply), the other side is filled with 0.3 N NaOH solution (which will be connected to the positive terminal of the power supply). Current is measured at every 30 minutes up to 6 h. Chloride contamination and temperature at every 30 min were also monitored. From the results using current and time, chloride permeability is calculated in terms of Coulombs at the end of 6 h.

3.7. Impressed voltage test

Cylindrical concrete specimens of size 50 mm diameter and 100 mm height were cast using 1:1.50:3.0 mix ratio ($W/C = 0.53$) with centrally embedded rebar of 12 mm diameter and 100 mm height, containing ordinary Portland cement (control) and OPC replaced by rice husk ash at 5%, 10%, 15%, 20%, 25% and 30% replacement levels. During casting, the moulds were mechanically vibrated. After 24 h, the cylindrical specimens were demoulded and subjected to water curing for 28 days. After curing, the specimens were subjected to impressed voltage test. In this technique, the concrete specimens were immersed in 5% NaCl solution and embedded steel in concrete is made anode with respect to an external stainless steel electrode serving as cathode by applying a constant positive potential of 12 V to the system from a DC source. The variation of current is recorded with time. For each specimen, the time taken for initial crack and the corresponding maximum anodic current flow was recorded. Triplicate specimens were used for this technique.

3.8. Open circuit potential measurements (OCP)

Triplicate concrete specimens of size $100 \times 100 \times 100$ mm were caste using 1:1.50:3.0 mix ratio containing water to cement ratio 0.53 with 12 mm diameter rebar of 120 mm length rebar were embedded at a cover of 25 mm from one side of the cube specimen. The concrete cubes were cast with ordinary Portland cement (control) and OPC replaced by rice husk ash at 5%, 10%, 15%, 20%, 25% and 30% replacement levels. During casting, the rebars were cleaned with pickling acid before embedded in concrete. After casting the specimens were subjected to water curing for 28 days. After 28 days of curing the cubes were taken out and dried for 24 h and subjected to alternate wetting and drying in 3% NaCl solution. One cycle consists of seven days immersion in 3% NaCl solution and seven days drying in open atmosphere. The tests were continued over a period of 200 days. Open circuit potential measurements were monitored with reference to saturated calomel electrode (SCE) periodically with time as per ASTM C876. From the results potential vs. time plot is drawn using the average potentials obtained.

4. Results and discussion

4.1. Compressive strength

Table 2 shows the compressive strength of rice husk ash replaced concrete after 7, 14 and 28 days of curing. From the table, it is found that the compressive strength increases with blending percentage and with age. This value is pronounced for all replacement levels. Higher concentration of RHA also can be used without strength loss. After 28

Table 2
Compressive strength of rice husk ash replaced concrete after 7, 14 and 28 days of curing

% of replacement	Average compressive strength (N/mm^2)		
	7 days	14 days	28 days
0(OPC)	27.22	33.29	36.45
5	31.32	35.62	36.49
10	30.45	35.97	37.43
15	31.52	35.04	37.38
20	31.64	36.17	37.71
25	33.09	35.27	39.55
30	33.53	35.44	37.80

days of curing also all the rice husk ash replaced concretes are showing a higher compressive strength than the control concrete. After 28 days of curing, conventional and 5% rice husk ash replaced concretes are showed equal compressive strength. Rice husk ash blended concretes showed higher compressive strength than control concretes beyond 5% replacement levels. Upto 30% replacement level of rice husk ash there is no decrease in compressive strength observed when compared to conventional OPC concrete. Nehdi et al. [14] also found the same observation in compressive strength increase.

4.2. Split tensile strength

The split tensile strength of rice husk ash blended concrete up to 30% replacement levels after 28 days curing are shown in Table 3. It can be observed from the table that, up to 25% replacement of rice husk ash the split tensile strength has not been affected. After 25% replacement level, a slight decrease in split tensile strength is observed.

4.3. Bond strength

Table 4 shows the bond strength results of OPC and rice husk ash replaced concrete after 28 days of curing. From the table it is observed that, all the rice husk replaced concretes are showing higher bond strength values than the conventional concrete. So the replacement of rice husk ash does not affect the bond strength properties.

Table 3
Split tensile strength of rice husk ash replaced concrete after 28 days of curing

Sl. no.	% of replacement	Split tensile strength (N/mm^2)
1	OPC	4.49
2	5	4.57
3	10	4.65
4	15	4.92
5	20	4.60
6	25	4.58
7	30	3.67

Table 4
Bond strength of different percentages of rice husk ash replaced concrete after 28 days of curing

Sl. no.	% of replacement	Bond strength (N/mm^2) at 0.25 mm slip
1	OPC	3.32
2	5	4.11
3	10	4.31
4	15	3.79
5	20	3.43
6	25	4.07
7	30	3.87

Table 5
Porosity of rice husk ash replaced concrete at various percentages

Sl. no.	% of replacement	Effective porosity (%)
1	OPC	18.06
2	5	18.18
3	10	13.82
4	15	13.80
5	20	13.54
6	25	13.04
7	30	11.89

4.4. Effective porosity test

Table 5 shows the porosity values of OPC and different percentage of rice husk ash replaced concrete after 28 days curing. From the table, it is observed that the porosity values decreases as the percentage of replacement increases. It has also been reported that at early age of curing (7 and 28 days) supplementary cementitious materials are more porous than the plain cement paste and the pore size distributions are more porous, but at the later ages (90 days) this may be reversed. They have also reported that pozzolanic materials increased the porosity and reduced the pore structure [13]. The same trend is observed in this case also. The small RHA particles improved the particle packing density of the blended cement, leading to a reduced volume of larger pores.

4.5. Coefficient of water absorption

Table 6 indicates the coefficient of water absorption of OPC and different percentages of rice husk ash replaced

Table 6
Coefficient of water absorption of rice husk ash replaced concretes

Sl. no.	% of replacement	Coefficient of water absorption (m^2/s)
1	Control(OPC)	3.5571×10^{-10}
2	5	6.7587×10^{-11}
3	10	1.0320×10^{-11}
4	15	1.0644×10^{-11}
5	20	1.2122×10^{-10}
6	25	1.4548×10^{-10}
7	30	1.3030×10^{-10}

Table 7
Chloride diffusivity of rice husk ash replaced concrete

Sl. no.	% of replacement	Charge passed in Coulombs
1	OPC	1161
2	5	1108
3	10	653
4	15	309
5	20	265
6	25	213
7	30	273

Table 8
Impressed voltage test results of OPC and various percentage of rice husk ash replaced concrete

Sl. no.	% of replacement	Time to cracking (h)
1	OPC	42
2	5	72
3	10	74
4	15	No cracking even after 144 h of exposure
5	20	No cracking even after 144 h of exposure
6	25	No cracking even after 144 h of exposure
7	30	No cracking even after 144 h of exposure

concrete after 28 days curing. From the table it is observed that, the coefficient of water absorption for rice husk ash replaced concrete at all replacement levels is found to be less when compared to control concrete.

4.6. Rapid chloride ion penetration test

Table 7 shows the rapid chloride permeation test results of rice husk ash replaced concrete after 28 days curing. From the table it is found that as the replacement level increases the charge passed decreases. Replacement of rice husk ash drastically reduced the Coulomb values. As the replacement level increases, the chloride penetration decreases. As per ASTM C1202, RHA reduced the rapid chloride penetrability of concrete from a low to very low ratings from higher to lower replacement levels. The same trend was reported by Nehdi et al. [14] in RHA replaced concrete.

4.7. Impressed voltage test

Table 8 shows the impressed voltage test results of OPC and various percentage of rice husk ash replaced concrete after 28 days curing. In this test, there is no cracking observed in 15%, 20%, 25% and 30% rise husk ash replaced concretes even after 144 h of exposure. Whereas in ordinary Portland cement concrete, the specimen was cracked even after 42 h of exposure in 5% NaCl solution. The concrete specimens containing 5% and 10% rise husk also failed within 72 and 74 hours of exposure. This indicates that the replacement of rice husk ash refined the pores and thereby the permeability and corrosion gets reduced.

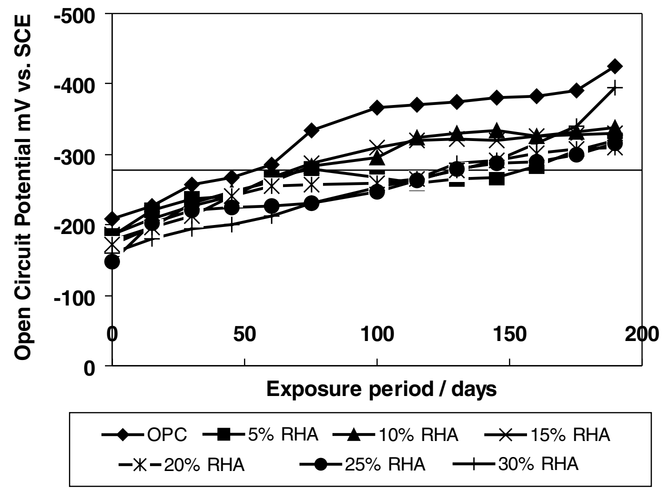

Fig. 1. Potential-time behaviour of rice husk ash replaced concrete.

4.8. Open circuit potential measurements (OCP)

The embedded steel potentials measured periodically against saturated calomel electrode (SCE) with time for different replacement levels of rice husk ash are shown in Fig. 1. As per ASTM C876-97 systems showing open circuit potential values lesser than −275 mV vs. SCE is considered to be passive in condition. From the figure it is observed that, all the rice husk ash replaced concretes have shown less negative potential than −275 mV even up to 100 days of exposure indicating the passive condition of the rebars. Beyond 100 days of exposure all the systems are showing a more negative potential than −275 mV vs. SCE irrespective of the replacement ratio showing the active condition of rebars.

5. Conclusion

From the above investigations it is found that the incorporation of RHA up to 30% replacement level reduces the chloride penetration, decreases permeability, improves strength and corrosion resistance properties. From this study it is concluded that the replacement level of RHA is recommended up to 25%.

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