

Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete

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Abstract

In this study, rice husk ash (RHA) prepared from the boiler burnt husk residue of a particular rice mill has been evaluated for optimal level of replacement as blending component in cements. The physical, chemical and mineralogical characteristics of RHA were first analysed. The properties of concrete investigated include compressive strength, splitting tensile strength, water absorption, sorptivity, total charge-passed derived from rapid chloride permeability test (RCPT) and rate of chloride ion penetration in terms of diffusion coefficient. This particular RHA consists of 87% of silica, mainly in amorphous form and has an average specific surface area of 36.47 m²/g. Test results obtained in this study indicate that up to 30% of RHA could be advantageously blended with cement without adversely affecting the strength and permeability properties of concrete. Another interesting observation emanating from this study is the linear relationship that exists among water sorptivity, chloride penetration and chloride diffusion.

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1. Introduction

Rice husk is an agricultural residue obtained from the outer covering of rice grains during milling process. It constitutes 20% of the 500 million tons of paddy produced in the world [1]. Initially rice husk was converted into ash by open heap village burning method at a temperature, ranging from 300 °C to 450 °C [2]. When the husk was converted to ash by uncontrolled burning below 500 °C, the ignition was not completed and considerable amount of unburnt carbon was found in the resulting ash [3]. Carbon content in excess of 30% was expected to have an adverse effect upon the pozzolanic activity of RHA [4]. The ash produced by controlled burning of the rice husk between 550 °C and 700 °C incinerating temperature for 1 h transforms the silica content of the ash into amorphous phase [5,6]. The reactivity of amorphous silica is directly propor-

tional to the specific surface area of ash [7,8]. The ash so produced is pulverized or ground to required fineness and mixed with cement to produce blended cement.

Several papers have been published on the performance of RHA blended concrete. However, only limited information is available on the permeability characteristics. The objective of the present investigation is to evaluate the rice mill boiler burnt rice husk residue as supplementary cementitious material with reference to strength and permeability properties of hardened concretes and identify the optimal level of replacement. In the present context, optimal level refers to the maximum favorable percentage of replacement of OPC with RHA up to which the strength and permeability properties of blended concrete are equivalent or more than that of unblended OPC concrete. Towards this end, experiments were carried out in two phases as per standard test procedures. In the first phase, chemical composition, physical properties, and characterization of RHA were carried out. This included evaluation of standard consistency, initial setting time, final setting time

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and compressive strength of RHA blended cements. In the second phase, studies on concrete specimens were conducted. This included tests on compressive strength, splitting tensile strength, water absorption, coefficient of water absorption, sorptivity, resistance to chloride ion penetration and diffusion coefficient. All the experiments were carried out in triplicate and mean values are reported.

2. Materials and methods

2.1. Materials used

Ordinary Portland cement (OPC) conforming to Indian standard code IS 8112-1995 was used. Graded river sand passing through 1.18 mm sieve with fineness modulus of 2.85 and specific gravity of 2.55 was used as fine aggregate. Locally available crushed granite aggregate, passing through 12.5 mm sieve while being retained on 4.75 mm sieve with fineness modulus of 6.26 and specific gravity of 2.7. (Conforming to IS 383-1970) was used as coarse aggregate.

Boiler-fired rice husk residue was collected from a modern rice mill at Pudukkottai, Sivaganga district in Tamil Nadu, India. The uncontrolled fired husk residue ash was black in colour obviously due to excess amount of carbon content. The mill fired husk residue ash was further burnt in an industrial furnace at a temperature of 650 °C over a period of 1 h as described below.

The uncontrolled fired husk residue collected from the mill was placed in the furnace. The temperature of the furnace was increased at a rate of 200 °C per hour until it reached the required temperature of 650 °C over a period of 3 h and 15 min. At 650 °C, the temperature was kept constant for a burning time of 1 h; under controlled condition and then cooled. The material was pulverized to a mean grain size of 3.8 µm before it was used as a cement replacement material.

2.2. Physical and chemical analysis of OPC and RHA

Particle size distribution of OPC and RHA was determined using HORIBA LA-910 particle size analyzer. Mineralogical analysis of RHA was carried out by X-ray diffraction analysis. Specific surface area of OPC was measured as per IS 4031 (part 2)-1995 using Blain's air permeability apparatus. Specific surface area of RHA was measured using BET's method by nitrogen adsorption. Physical properties such as specific gravity, bulk density, and fineness of OPC and RHA were determined as per IS 4031 (parts)-1995 and IS 1727-1995. Chemical analysis for oxide composition of OPC and RHA was determined as per IS 4032-1985 and IS 1727-1995.

2.3. Blended cements

RHA blended cements were prepared by replacing OPC with different amount of RHA (5%, 10%, 15%, 20%, 25%,

30% and 35% by weight of cement) in dry condition. The mixtures were thoroughly homogenized and kept in polythene bottles.

2.4. Consistency and setting time of blended cement

Standard consistency of RHA blended cements was determined in accordance with IS 4031 (Part 4)-1995. Pastes having standard consistency were used to determine the initial setting time and final setting time in accordance with IS 4031 (Part 5)-1995.

2.5. Compressive strength of blended cement mortar cubes

The compressive strength of RHA blended cement mortar cube specimens of 70.6 mm size with a water binder ratio appropriate to standard consistency measurement was determined after 1, 3, 7 and 28 days of moisture curing as per IS 4031(Part 6)-1995. Mortar mixes were designated as M0 for control and M1-M7 for RHA blended mortars. The RHA blended cement mortar mix proportions are presented in Table 1.

2.6. Mix proportions and casting of concrete specimens

In the second phase, eight different proportions of concrete mixes (RHA ranging from 5% to 35% by weight of cement) including the control mix were prepared with a water to binder W/(C + RHA) ratio of 0.53 for a design cube compressive strength of 25 MPa. These mixes were designated as R0 for control and R1-R7 for RHA concretes. The mix proportions are presented in Table 2.

The concrete was mixed for 5 min in a laboratory drum mixer. For mixes R0 through R7, twelve cube specimens of 100 mm size were cast from each mix for compressive strength testing. Three cylindrical specimens of 150 mm diameter and 300 mm height were also cast from each mix for determining the splitting tensile strength. Thirty cylindrical specimens of 100 mm diameter and 50 mm height were cast from each mix for water and chloride penetration tests. After casting, all the specimens were left covered in the casting room for 24 h. The specimens were then demoulded and transferred to moisture curing room until the time of testing.

2.7. Compressive strength of concrete

Compressive strength of RHA blended cement concrete cubes was determined as per IS 9013-1997 after 7, 14, 28 and 90 days of moisture curing.

2.8. Splitting tensile strength of concrete

Splitting tensile strength test was conducted on RHA blended concrete cylinders as per IS 5816-1999 after 28 days of moisture curing.

Table 1
Mix proportion and compressive strength of RHA blended cement mortars

Mix designation	RHA (%)	Compressive strength (MPa)			
		One day	Three days	Seven days	28 Days
M0 (control)	0	11.6	20.9	27.2	37.0
M1	5	12.0	22.1	27.4	38.9
M2	10	12.8	24.4	27.8	42.8
M3	15	13.8	28.9	29.3	46.7
M4	20	12.2	24.8	28.3	39.8
M5	25	11.7	23.6	27.6	38.3
M6	30	11.1 ^a	20.7 ^a	27.4 ^a	37.0 ^a
M7	35	10.4	18.4	26.4	36.0

Binder to sand ratio of 1:3.

^a Equivalent strength compared to control specimen.

Table 2
Mix proportion of RHA blended concretes

Mix designation	RHA (%)	Quantities (kg/m ³)		Slump (mm)
		Cement	RHA	
R0 (control)	0	383	0	98
R1	5	364	19	106
R2	10	345	38	115
R3	15	326	57	91
R4	20	306	77	81
R5	25	287	96	74
R6	30	268	115	64
R7	35	249	134	41

Water to binder ratio [C + RHA] 0.53; sand 575 kg/m³; and aggregate 1150 kg/m³.

2.9. Water absorption

Percentage of water absorption is a measure of the pore volume or porosity in hardened concrete, which is occupied by water in saturated condition. Water absorption values of RHA blended concrete specimens were measured as per ASTM C 642 after 28 and 90 days of moisture curing.

2.10. Coefficient of water absorption

Coefficient of water absorption is suggested as a measure of permeability of water [9]. This is measured by the rate of up take of water by dry concrete in a period of 1 h. The concrete specimens were preconditioned by drying in an oven at 105 °C for seven days until constant weight was reached and then allowed to cool in a sealed container for three days. The sides of the concrete samples were coated with transparent epoxy resin in order to allow the flow in one direction. Then the samples in a vertical position were kept partially immersed to a depth of 5 mm at one end while the rest of the portions were kept exposed to the laboratory air as shown in Fig. 1. The quantity of water absorbed during the first 60 min was calculated. Coefficient of water absorption values of RHA blended concrete specimens after 28 and 90 days of moisture curing were determined using the formula,

$$K_a = \left[\frac{Q}{A} \right]^2 \times \frac{1}{t}$$

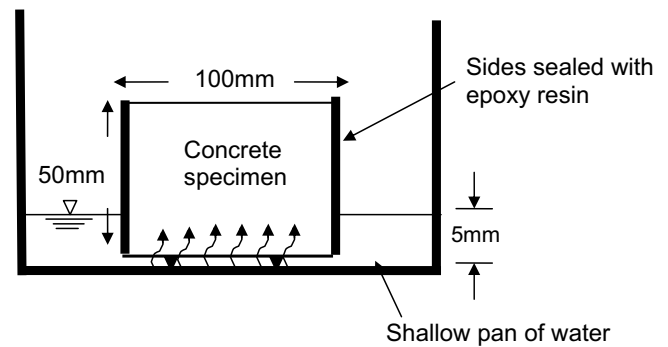


Fig. 1. Coefficient of water absorption test and sorptivity test.

where K_a is the coefficient of water absorption (m²/s), Q is the quantity of water absorbed (m³) by the oven dry specimen in time (t), t is 3600 s and A is the surface area (m²) of concrete specimen through which water penetrates.

2.11. Sorptivity

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material [10]. Concrete specimens were preconditioned by drying in an oven at 50 °C for four days and then allowed to cool in a sealed container for three days. The sides of the concrete specimens were coated with transparent epoxy resin in order to allow the flow in one direction. The initial mass of the sample was taken and at time 0, the specimen was kept partially immersed to a depth of 5 mm in the water as shown in Fig. 1.

At selected times (typically 1, 2, 4, 8, 10, 20, 30... 110 and 120 min), the sample was removed from the water, excess water blotted off with a damp paper towel and then the sample was weighed. It was then replaced in the water for the selected time period. The gain in mass per unit area over the density of water was plotted versus the square root of the elapsed time. The slope of the line of best fit of these points was taken as the sorptivity value. The sorptivity values of RHA blended concrete specimens after 28 and 90 days of moisture curing were calculated by the following formula [11],

$$i = St^{1/2}$$

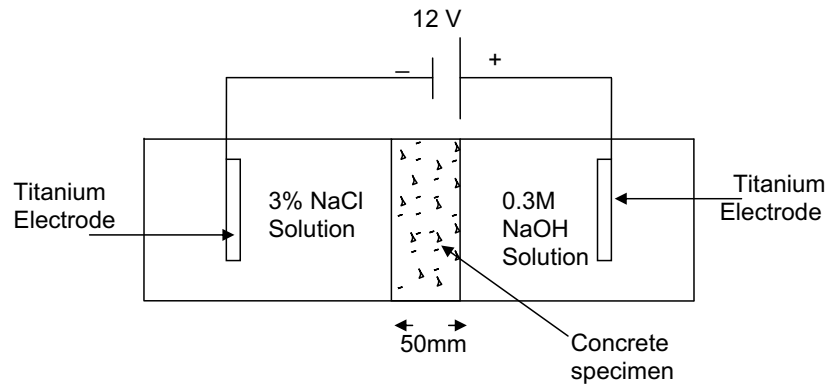


Fig. 2. Chloride diffusion test.

where i is the cumulative water absorption per unit area of inflow surface (m^3/m^2), S is the sorptivity ($\text{m}/\text{s}^{1/2}$) and t is the time elapsed (s).

2.12. Chloride penetration

The resistance to chloride ion penetration in terms of total charge passed in coulombs through RHA blended concrete specimens after 28 and 90 days of moisture curing were measured as per ASTM C 1202.

2.13. Chloride diffusion

In this test, concrete specimen was fixed in between two compartments of a diffusion cell containing 3% NaCl solution in one compartment and 0.3 M NaOH solution in the other compartment as shown in Fig. 2. A DC potential of 12 V was applied between two titanium electrodes placed in the solutions. The amount of chloride ion migrating through the RHA blended concrete specimens after 28 and 90 days of moisture curing was monitored by periodically removing small aquilots and determining the chloride concentration of these samples, until steady state was reached (120 h). Chloride diffusion coefficients were calculated using Nernst–Einstein equation [12].

$$D = \frac{JRTL}{ZFC_0E}$$

where D is the chloride diffusion coefficient (cm^2/s), J is the flux of chloride ions ($\text{mol}/\text{cm}^2\text{s}$), R is the gas constant (8.314 J/K mol), T is the absolute temperature (K), L is the thickness of the specimen (cm), Z is the valency of chloride ion ($Z = 1$), F is the Faradays constant ($9.648 \times 10^4 \text{ J/Vmol}$), C_0 is the initial chloride ion concentration (mol/l), and E is the potential applied (12 V).

3. Results and discussion

3.1. Physical and chemical analysis of OPC and RHA

The particle size distribution curves of OPC and RHA are shown in Fig. 3. The particles of RHA are nearly six

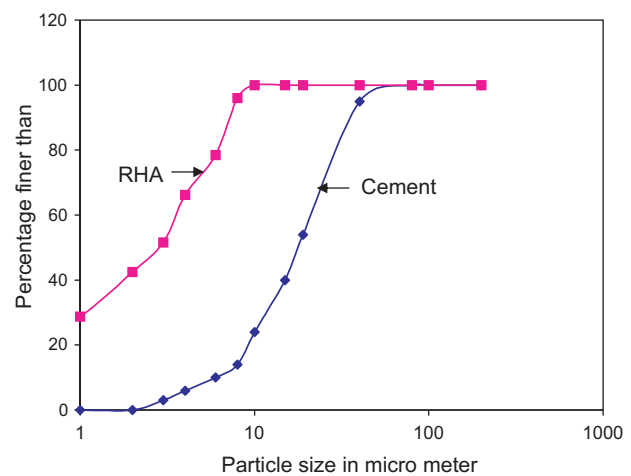


Fig. 3. Particle size distribution curves of OPC and RHA.

times finer than those of OPC and the finer particles of RHA are well graded in their distribution. Mineralogical analysis of RHA carried out by X-ray diffraction showed that the silica was mostly in amorphous form. Small quantities of crystal-phase as quartz, coesite (silicon dioxide) and cristobalite are also present.

The physical properties of OPC and RHA are compared in Table 3. The average specific surface area of RHA is $36.47 \text{ m}^2/\text{g}$ (BET's) and that of OPC is $326 \text{ m}^2/\text{kg}$ (Blain's). The density, specific gravity and mean grain size of RHA are found to be less than those of OPC.

Chemical composition data for OPC and RHA are compared in Table 4. This particular RHA consists 87% of silica. The loss on ignition value for RHA is 2.1%, which is

Table 3
Physical properties of OPC and RHA

Materials	Bulk density (g/cm^3)		Specific gravity	Fineness passing 45 μ sieve	Specific surface (Blain's) (m^2/kg)	Specific surface (BET) (m^2/g)	Mean grain size (μm)
	Dense	Loose					
OPC	1.56	1.16	3.1	85	326	–	22.50
RHA	0.49	0.40	2.06	99	–	36.47	3.80

Table 4
Chemical composition of OPC and RHA (%)

Material	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	Loss on ignition
OPC	20.25	5.04	3.16	63.61	4.56	0.08	0.51	3.12
RHA	87.32	0.22	0.28	0.48	0.28	1.02	3.14	2.10

less than that of OPC. The resulting RHA was whitish gray in colour. Colour changes are associated with the completeness of the combustion process as well as structural transformation of the silica in the ash. Thus, whitish gray colour of the resulting ash is an indication of complete oxidation of the carbon in the ash [5].

3.2. Consistency and setting time of blended cement

The percentage of cement replacement level (CRL) versus standard consistency graph (Fig. 4) indicates that the water required for standard consistency linearly increases with an increase in RHA content. As ashes are hygroscopic in nature and the specific surface area of RHA is much higher than cement, it needs more water.

The percentage of CRL versus initial and final setting time chart (Fig. 5) shows that up to 15%, increasing the

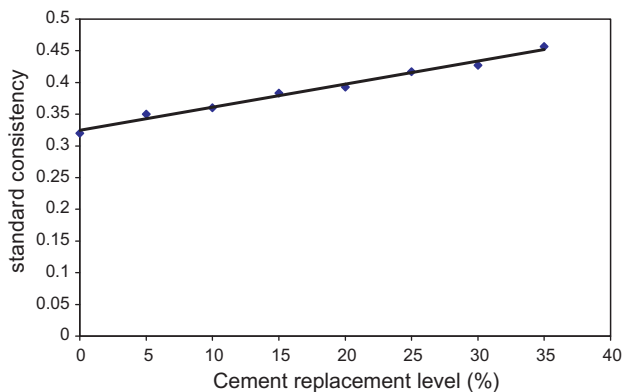


Fig. 4. Standard consistency of RHA blended cements.

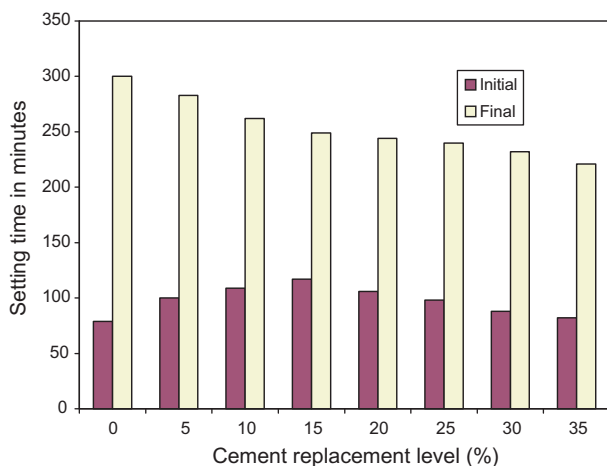


Fig. 5. Initial and final setting times of RHA blended cements.

RHA level increases the initial setting time. At 20%, 25%, 30% and 35%, there is a decrease in initial setting time. The initial setting time measured for RHA blended cements up to 35% is higher than that of control OPC. On the other hand the final setting time continues to decrease with the increase in RHA up to 35%. The final setting time measured for 0% and 30% CRL is found to be 300 min and 232 min, respectively. These values are well within the permissible limits as per IS 8112-1995. Cook [4] and Bhanumathidas and Mehta [1] have also made similar observations.

3.3. Compressive strength of blended cement mortar cubes

The compressive strengths of RHA blended cement mortars are shown in Table 1. Comparison of the data for 1, 3, 7 and 28 days of curing time shows that the compressive strength increases with RHA up to 15% and then the compressive strength decreases. However, at 30% RHA, the compressive strength of mortar attains the equivalent value as observed for control mortar. At 35% RHA, the compressive strength decreases to a value which is lower than that of control concrete. Thus, 30% replacement of OPC with RHA is considered as the optimal limit.

The increase in strength may be due partially to the pozzolanic reaction as reported by many researchers [3,4,13–16] and partially to high specific surface area and the presence of reactive silica in RHA. Al-Khalaf et al. [3] showed that compressive strength development in 1:3 RHA blended cement mortars of same consistency with 30% cement replacement reached the same strength as those of control mortar.

3.4. Compressive strength of concrete

The compressive strengths of RHA blended concrete specimens are shown in Table 5. Comparison of the data for 7, 14, 28 and 90 days of curing time shows that the compressive strength increases with RHA up to 20% and then at 30% RHA, the compressive strength of concrete attains values equivalent to that of control concrete specimens. At 35% RHA, the compressive strength decreases to a value which is lower than that of control concrete. Therefore, 30% RHA seems to be the optimal limit.

Zhang and Malhotra [16] observed that the compressive strength of concrete containing up to 30% RHA was higher than that of control concrete at 7, 14, 28 and 90 days. Bhanumathidas and Mehta [1] also confirmed that in general, the 90 days compressive strength with RHA up to 40% was higher than the corresponding concrete mixtures

Table 5
Compressive strength of RHA blended concrete

Mix designation	RHA (%)	Compressive strength (MPa)			
		Seven days	14 Days	28 Days	90 Days
R0 (control)	0	27.2	32.3	37.1	38.3
R1	5	27.6	34.2	40.0	43.3
R2	10	28.0	35.3	41.3	44.8
R3	15	29.3	36.0	41.8	45.7
R4	20	29.7	39.3	42.5	46.0
R5	25	28.7	36.1	38.8	43.0
R6	30	27.4 ^a	33.5 ^a	37.6 ^a	38.7 ^a
R7	35	25.7	31.1	35.1	37.2

^a Equivalent strength compared to control specimens.

without RHA. The amorphous silica and the fine particle size of RHA are the principle reasons for the excellent pozzolanic activity and increase in compressive strength.

3.5. Splitting tensile strength

The splitting tensile strengths of RHA blended concretes after 28 days of curing are shown in Fig. 6. It can be clearly seen that the splitting tensile strength value increases with RHA content up to 20% and then at 30% RHA, the splitting tensile strength is equivalent to that of OPC concrete. Thus, 30% of RHA is the optimal limit.

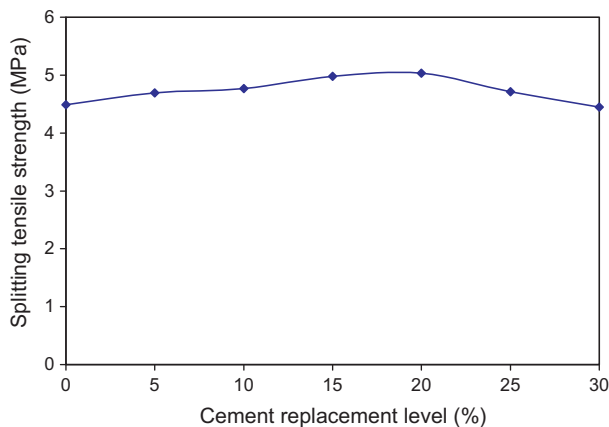


Fig. 6. Splitting tensile strength of RHA blended concretes.

3.6. Water absorption

Water permeability property as indicated by saturated water absorption of RHA blended concrete specimens after 28 and 90 days of curing are given in Table 6. It can be seen that at 28 days curing, the percentage of water absorption increases with RHA content up to 35%. This is due to the fact that RHA is finer than OPC and also it is hygroscopic in nature. When the curing time was increased to 90 days the percentage of water absorption values decreased considerably with increase in RHA content up to 25%. Even at 30% RHA, the value was lower compared to that of control. Obviously, with prolonged curing, addition of RHA leads to a reduction of permeable voids.

3.7. Coefficient of water absorption

The coefficients of water absorption of RHA blended concrete specimens are presented in Table 6. It can be seen that at 28 days of curing, coefficient of water absorption progressively decrease with increase in RHA content up to 25%. At 30% and 35% RHA there is an increase in coefficient of water absorption and these values are also lower than that of control concrete specimens. At 90 days of curing, the coefficient of water absorption values up to 35% are quite lower confirming that with prolonged curing addition of RHA leads to a reduction of permeable voids.

3.8. Sorptivity

The sorptivity values calculated for RHA blended concrete specimens after 28 and 90 days of curing are also presented in Table 6. It can be seen that at 28 days of curing, sorptivity progressively decreases with increase in RHA content up to 25%. At 30% and 35% RHA there is an increase in sorptivity and these values are also lower than that of control concrete. At 90 days of curing, the sorptivity values up to 35% RHA are quite lower than that of control concrete. This again confirms that prolonged curing leads to a reduction in pore space. It is also observed from the sorptivity data that 30% RHA concrete specimens have shown a 45% reduction in sorptivity at 28 days compared to that of control.

Table 6
Permeability related properties of RHA blended concretes

Mix designation	RHA (%)	Saturated water absorption (%)		Coeff. of water absorption $\times 10^{-10}$ (m ² /s)		Sorptivity $\times 10^{-6}$ (m/s ^{1/2})	
		28 Days	90 Days	28 Days	90 Days	28 Days	90 Days
R0 (control)	0	4.71	3.76	1.62	0.85	11.05	9.76
R1	5	4.83	3.21	1.42	0.71	10.60	7.09
R2	10	5.02	3.20	1.03	0.61	9.16	4.86
R3	15	5.58	3.11	0.99	0.46	7.37	4.09
R4	20	5.81	2.20	0.92	0.31	6.00	3.61
R5	25	6.09	2.80	0.51	0.20	5.53	2.28
R6	30	6.35	3.05	1.06	0.43	6.08	3.38
R7	35	6.92	3.98	1.51	0.58	10.30	4.04

3.9. Chloride penetration

The rapid chloride permeability test results for RHA blended concrete specimens are shown in Fig. 7. It can be seen that the total coulombs charge passing through RHA blended concrete specimens continuously decreases with increase in RHA content up to 30%. At 35% RHA there is an increase in total charge passed value and this value is also lower than that of control concrete. This observation is true for both 28 and 90 days cured specimens. Chloride permeability is considerably reduced by partial replacement of OPC with RHA up to 30%. Particularly the total charge passed for 30% RHA blended concrete is considerably reduced (more than 70% reduction) both at 28 and 90 days cured concretes. Since the total charge passed through the concrete depends on the electrical conductance, the lower unburnt carbon content (loss on ignition value 2.1%) present in RHA might have contributed to the significant reduction in the electrical charge passed. It is worth mentioning that the unburnt carbon particles may contribute to the conductivity of the medium and a reduction in the unburnt carbon content may be beneficial from the chloride permeability point of view.

3.10. Chloride diffusion

The chloride diffusion coefficients of RHA blended concrete specimens are presented in Fig. 8. It can be seen that the diffusion coefficient of RHA blended concrete specimens continuously decreases with increase in RHA content up to 25% of RHA. At 30% and 35% RHA, there is an increase in diffusion coefficient and these values are also lower compared to that of control. This observation is true for both 28 and 90 days cured specimens. Thus, chloride diffusion is also considerably reduced by partial replacement of OPC with RHA. There is a 28% reduction in chloride diffusion coefficient for 30% RHA blended concrete compared to control.

The transport of chloride ions through RHA blended concretes depends on the pore structure of the concrete while the electrical conduction depends on both pore structure characteristics and electrical conductivity of the pore solution [17–19]. The finer particles of ashes develop dis-

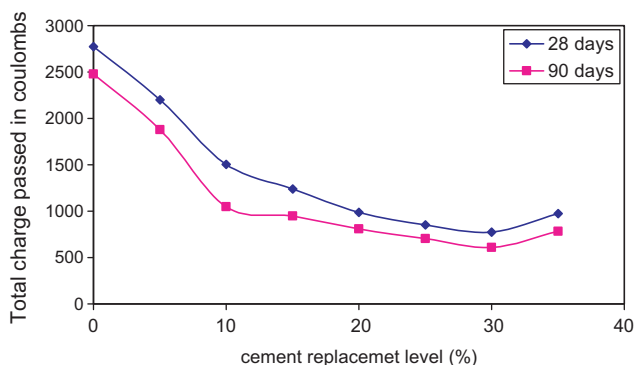


Fig. 7. Chloride permeability of RHA blended concretes.

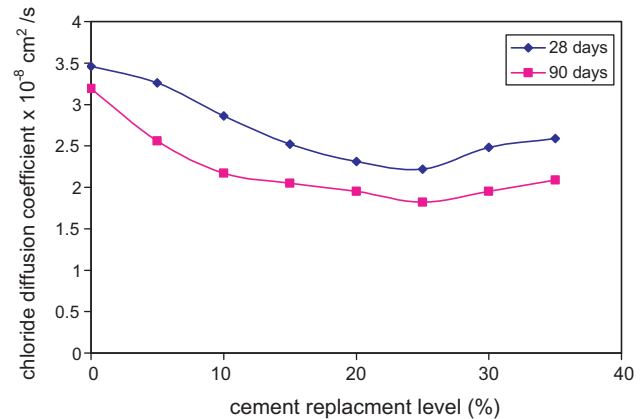


Fig. 8. Chloride diffusion of RHA blended concretes.

continuous and tortuous pore in concrete structure [20]. Moreover the micro and macro pores present in the concrete are completely filled up by finer particles. Cook [4] has reported that highly reactive pozzolana, such as rice husk ash is able to reduce the size of voids in hydrated cement pastes, thus, making them almost impermeable even at early age (7–28 days). Bhanumathidas and Mehta [1] also confirmed the pore-refining capacity of RHA when present in a Portland cement concrete. The decrease in chloride permeability is promoted with an increase in fineness of the ashes [21]. The present work indicates that the impermeability properties are considerably improved due to pore refinement by the finer particles of RHA in blended concretes.

The previous discussion clearly points out the strong dependence of rapid chloride permeability measured in terms of total charge passed in coulombs on the chloride diffusion coefficients. The total charge passed is correlated with chloride diffusion coefficient in Fig. 9. For both 28 and 90 days of curing the chloride diffusion coefficients increases linearly with measured total charge passed. The values of correlation coefficients for both 28 and 90 days of curing are close to unity indicating fairly good linear

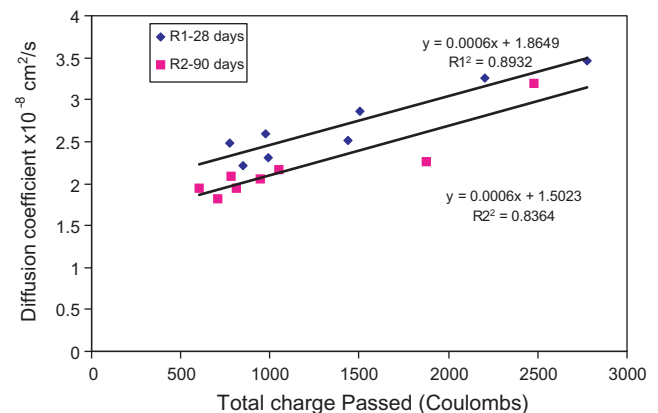


Fig. 9. Correlation between total charge passed and chloride diffusion coefficient.

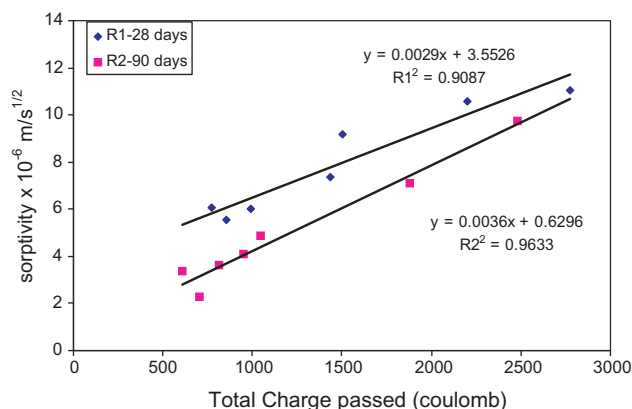


Fig. 10. Correlation between total charge passed and sorptivity.

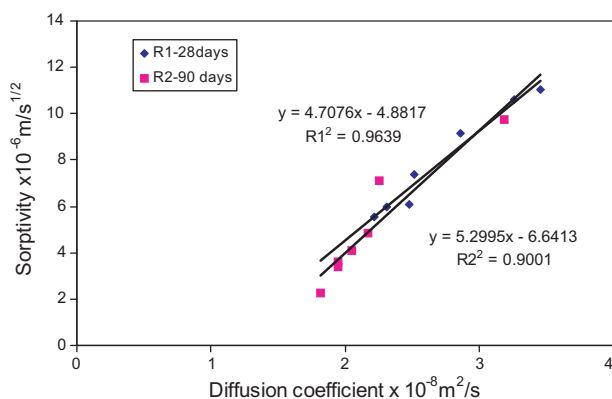


Fig. 11. Correlation between diffusion coefficient and sorptivity.

correlation between charge passed values and diffusion coefficients.

Further to quantify the type and nature of interdependence among the three measured properties (sorptivity, total charge passed and chloride diffusion coefficient) at 28 and 90 days of curing, the total charge passed data is correlated with sorptivity (Fig. 10); and also chloride diffusion coefficient is correlated with sorptivity (Fig. 11). From Fig. 10, it is evident that for both 28 and 90 days of curing charge passed increases linearly with sorptivity values. It can be seen from Fig. 11 that good correlation exists between chloride diffusion coefficient and sorptivity for both 28 and 90 days of curing of RHA concretes.

4. Conclusions

- (1) Rice husk ash obtained from Indian paddy when reburnt at 650 °C for a period of 1 h transforms itself into an efficient pozzolanic material rich in amorphous silica content (87%) with a relatively low loss on ignition value (2.1%).
- (2) As high as 30% by weight of OPC can be replaced with reburnt rice husk ash without any adverse effect on strength and permeability properties.

- (3) Replacement with 30% of reburnt rice husk ash leads to substantial improvement in the permeability properties of blended concrete when compared to that of unblended OPC concrete, namely
 - (a) About 35% reduction in water permeability.
 - (b) About 28% reduction in chloride diffusion.
 - (c) About 75% reduction in chloride permeation.
 These observations have a direct bearing on the durability of reinforced concrete constructions leading to an enhanced design life.
- (4) A linear relationship is found to exist among three measured transport properties, namely sorptivity, chloride penetration in term of total charge passed in coulombs and chloride diffusion coefficient.
- (5) In the case of compressive strength and chloride permeation properties, standard practice of curing for 28 days is found to be adequate. Prolonged curing up to 90 days is found to be beneficial only from the point of view of improving the resistance to water absorption.
- (6) When rice husk ash which has a lower loss on ignition value compared to OPC is used to partially replace OPC, resistance to chloride permeation is substantially improved. This may be probably due to a decrease in electrical conductivity of concrete due to lowering of unburnt carbon content in RHA, in addition to pore structure refinement and conductivity of pore solution.

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