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Improved Durability Performances in Cement Mortar with Rice Husk Ash

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Currently many researches have been performed for enhancing durability of concrete. Rice husk ash has several advantages like early strength of concrete and dense pore structure. A calcium silicate hydrate (CSH) gel around the cement particles due to pozzolanic reaction of rice husk can increase the strength of concrete against cracking. Very limitedly a systematic and detailed investigation on the corrosion performance of rice husk ash and silica fume blended concrete is performed.
A realistic approach has been made through compressive strength, bond strength, and split tensile strength etc. Corrosion performance was also evaluated rapid chloride ion penetration test (RCPT) and impressed voltage test, and the results were discussed in the paper.

Keywords : Durability, Rice husk, Pozzolanic admixture, Silica fume, RCPT

1. INTRODUCTION

Concrete is the most widely used man made construction material in the world. Ordinary Portland Cement (OPC) is used as energy intensive and costly ingredient in the production of concrete. The manufacture of OPC is expensive and skill intensive process, besides polluting the environment heavily. Production of cement mainly is associated with the emission of carbon dioxide which is a significant source of global warming. Pozzalonic materials are widely used in concrete and mortars for various reasons, particularly for reducing the amount of cement required for making concrete and mortar which lead to a reduction in construction cost. Moreover most pozzolanic materials are by-product materials and the use of these materials leads to reduction in waste and save in energy consumption to produce cement. Most recently blended and multi-blended cement by incorporating industrial by-products/pozzolanic materials is becoming an active area of research because of their improved properties such as workability (Saraswathy et al., 2001, 2002, 2003a,b), long-term strength and durability (Muralidharen et al., 2004; Saraswathy et al., 2009; Mullick, 2007; Akaninyene et al., 2013). The common blending agents used are fly ash (FA), rice husk ash (RHA), palm oil fuel ash (POFA), slag, silica fume (SF), calcined clay etc (Song et al., 2006; Saraswathy and Song, 2006, 2007; Ahmed et al., 2008). The enhanced durability and structural performance in concrete with common mineral admixture can be found in the previous studies (Erdem et al., 2008; Chindaprasirt et al., 2005; Zhang and Gjørv, 1991).

Since RHA (Rice Husk Ash) is similar to SF (Silica Fume) in terms of pozzolanic activity because the former also contains significant amount of Silicon dioxide and a highly reactive pozzolanic material. The use of RHA as a partial replacement to cement will provide an economic use of the byproduct and consequently produce cheaper materials for low cost construction materials. 22% of the weight of paddy used to produce rice is received as husk. This husk contains about

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75% organic volatile matter and the balance 25% of the weight of this husk is converted into ash during the burning process known as rice husk ash. RHA are very high in silica content but the silica content is depends on the type of rice husk, method of firing and period of combustion. RHA can produced a pozzolanic activity but the pozzolanicity of RHA is depends on its chemical and physical properties. RHA with highly content silica in amorphous phase reported to react with cementitious binders to perform pozzolanic activity. According to, at temperatures around 40℃ and in the presence of water, the amorphous silica contained in rice husk ash can react with $Ca(OH)_2$ to form more Calcium Silicate Hydrates (CSH) gel [Chindaprasirt and Rukzon, 2008; Song et al., 2010, Ramezanianpour et al., 2009; Antiohos et al., 2007; Rukzon et al., 2009]. Thus the replacement of SF with RHA is one of the potential options to be considered.

2.1 Material used

Ordinary Portland cement (OPC)-43 Grade conforming to IS 8112 -1989 (equivalent to ASTM C150-Type-I) and local river sand passing through 2.36mm sieve having fineness modulus 2.2 conforming to Zone III of IS 383-1970 are prepared. Locally available well graded aggregates (normal size greater than 4.75mm and less than 16mm having fineness modulus of 2.72) are used. Specific gravity of fine and coarse aggregate are 2.41 and 2.78 respectively. Thermo mechanically Treated (TMT) rebar of size 12mm diameter and 70mm length was used. Locally available rice husk was burnt at 650℃ and the resulting ash was used for the investigation.

Silica fume obtained from Elkem enterprises was used. The chemical composition of OPC, RHA and SF are given in Table 1. The designations of different types of combinations used were given in Table 2. The used concrete mix is 1: 1.8: 3.69 with w/c ratio 0.55 (for bond strength). For mortar mix is 1: 3 with w/c ratio 0.52.

2.2 Tests carried out

2.2.1 Compression Test

The compressive strength of mortar is one of the most important properties of mortar. Mortar specimens of 100 x 100 x100mm cubes were cast with different types of blended cement mortars. After 24 hours the specimens were demoulded and subjected to curing for 28 days in ordinary tap water. After 28 days of curing, the cubes are then allowed to become dry for some hours.

Table 1. Chemical composition of OPC, SF and RHA

Compound	OPC	Silica fume (SF)	RHA
Silicon-di-oxide (SiO_2)%	20-21	98.2	85.49
Aluminium oxide (Al_2O_3)%	5.2-5.6	----	0.13
Ferric oxide (Fe_2O_3)%	4.4-4.8	0.3	0.45
Calcium oxide (CaO)%	62-63	0.2	3.68
Magnesium oxide (MgO)%	0.5-0.7	----	1.55
Sulphur-tri-oxide (SO_3)%	2.4-2.8	0.2	0.05
Loss on ignition (LOI)%	1.5-2.5	0.3	3.02
Sodium oxide (Na_2O)%	----	---	0.23
Potassium oxide (K_2O)	---	---	0.19

Table 2. Types of mixes used in this study

Mix designation	System
Control	OPC
S1	OPC +2% SF
S2	OPC +4% SF
S3	OPC+6% SF
S4	OPC+8% SF
R1	OPC+10% RHA
R2	OPC+15% RHA
R3	OPC+20% RHA
R4	OPC+25% RHA
R5	OPC+30% RHA
RS1	OPC+2% SF+10% RHA
RS2	OPC+2% SF+15% RHA
RS3	OPC+2% SF+20% RHA
RS4	OPC+2% SF+25% RHA
RS5	OPC+2% SF+30% RHA

2.2.2 Split tensile test

Split tensile test was carried out as per ASTM C496-90. Concrete cylinders of size 60mm diameters and 100mm height were cast using 1:3 mortar with w/c ratio of 0.52. During casting, the cylinders were mechanically vibrated using a table vibrator. After 24 hours, the specimens were removed from the mould and subjected to water curing for 28 days.

2.2.3 Test for density, permeable voids, and water absorption

The permeability of concrete is a measure of the rate at which a liquid will pass through it. The permeability of concrete depends upon its pore network, which arises from the excess water used during mixing and during initial hardening process. The overall porosity includes closed or logged pores in addition to a network of inter connected pores. Pore size ranges from a few angstroms to about 100 A° for the so called gel pores, from 100 to 100000 A° in capillary pores and a few millimeter in air or large pores. Inter connected pores endow the concrete permeability. In the present investigation, % of water absorption, % of permeable voids and % of total voids has been determined as per ASTM C 642-13.

2.2.4 Sorptivity test

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material. Cube specimens of 50mm height and 50mm thick were cast from each RHA and SF mixes for water sorptivity test. Initially the sides specimens were sealed with epoxy except top and bottom faces. The initial mass of the sample was taken and at time 0, the specimen was kept partially immersed to a depth of 5mm in the water for unidirectional flow of water as shown in the Fig. 1. Periodically up to one hour at an interval of every 5 minutes the specimens were removed from the water, excess water was blotted off with a damp paper towel and then the specimen was weighed. The gain in mass per unit area over the density of water is plotted versus the square root of the elapsed time. The slope of the line of best fit of these points is reported as the sorptivity. The sorptivity values of RHA blended and BA blended concrete specimens after 28 and 90 days of water curing were calculated by the following formula.

$$I = St^{1/2} \quad (1)$$

where I is Cumulative water absorption per unit area of inflow surface (m), S is Sorptivity (m/s$^{1/2}$), and T is Time elapsed (s).

2.2.5 Rapid chloride ion penetration test (RCPT)

This test was conducted as per ASTM C1202-09. Concrete disc of size 90mm diameters and 50mm thickness with and without rice husk ash and SF were cast and allowed to cure for 28 days. After 28 days curing, the concrete specimens were subjected to RCPT test by impressing a voltage of 60 V. Two halves of the specimens are sealed with PVC container of diameter 90mm. One side of the container is filled with 3% NaCl solution, the other side is filled with 0.3N NaOH solution. Current is measured at every 30 minutes up to 6 hours. Chloride contamination and temperature at every 30 min. was also monitored. From the results using current and time, chloride permeability is calculated in terms of Coulombs at the end of 6 hours.

2.2.6 Impressed voltage test

Cylindrical concrete specimens of size 50mm diameter and 100mm height were cast using 1:3 mix mortar with RHA and silica fume at various percentages of replacement containing W/C = 0.52, with centrally embedded rebar of 12mm diameter and 70mm height, containing OPC and OPC replaced by rice husk ash at 10%, silica fume at 2% and the combination of both silica fume and rice husk ash. After 28 days curing, the specimens were subjected to impressed voltage test. For each specimen, the time taken for initial crack and the corresponding

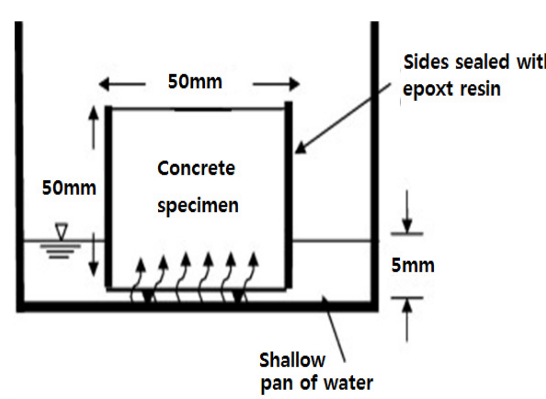

Fig. 1. Schematic of coefficient of sorptivity test

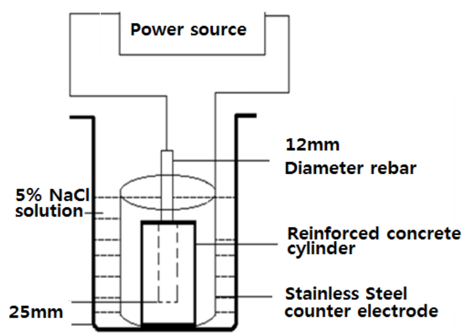

Fig. 2. Schematic representation of impressed voltage test

maximum anodic current flow was recorded. Triplicate specimens were used for this technique. In Fig. 2 schematic representation of impressed voltage test are shown.

2.2.7 Gravimetric weight loss determination

150mm size mortar cubes with 12mm dia. rebar of 70mm length were embedded at 25mm cover from one side of the specimen. The initial weight of the rebar was taken before embedment in the mortar. After casting, the specimens were cured for 28 days. Then all the specimens were subjected to alternate wetting and drying test. The process is continued for 60 days. After 60 days the specimens were broke open and the specimens were visually examined for its rust initiation. Then all the rebars were pickled in inhibited hydrochloric acid as per method prescribed in ASTM G1–1995 to remove the rust. Final weights of the rebars were measured. From the initial and final weight, loss in weight due to corrosion was determined.

From this, Corrosion rate was calculated as Eq.(3).

$$CR = 3650\, W / (DAT) \qquad (2)$$

where CR is corrosion rate, W is loss in weight (g), $D$is density of iron (g/cm^3), A is area of the bar(cm^2), T is time (days).

3. TEST RESULTS AND DISCUSSION

3.1 Physical test results

Compressive strength and RHA (10% to 30%) and SF (2 to 8%) replaced mortars after 28 days of curing period were reported in Fig. 3. From Fig. 3 it was inferred the 28 days compressive strength obtained for OPC (Control) mortar was 20MPa. The replacement of cement by SF (2%, 4%, and 6% & 8%) showed 17~21MPa and RHA replaced as (10~30%) showed 15~21MPa. The reactive silica present in RHA and SF favoured the formation of Calcium Silicate Hydrate (C.S.H) gel and enhanced the compressive strength at 10% replacement level. Above 20%, as the amount and unreactive silica was more, the non-stoichiometric ratio between $Ca(OH)_2$ and SiO_2 decreased the compressive strength values. The RHA replaced concretes showed higher or equal compressive strength values at 10% and 20% and SF replaced concrete showed equal performance at 2 and 4% when compared to OPC.

The 28 days split tensile strength data obtained for RHA (10%, 15%, 20%, 25% and 30%) and Silica fume 2%, 4%, 6% and 8% added mortars were reported in Fig. 4 and Table 3. From the table it was found that OPC control mortar showed

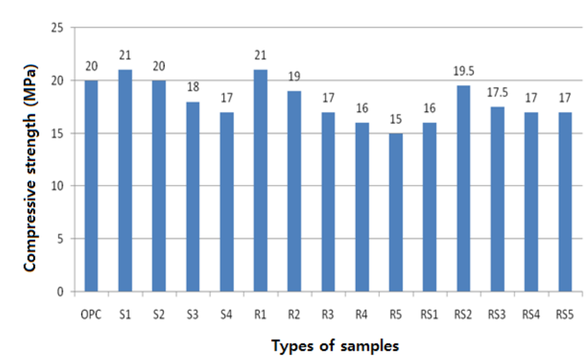

Fig. 3. Compressive strength of blended cement mortars

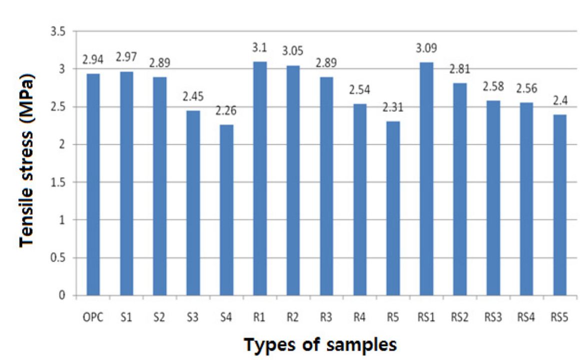

Fig. 4. Split tensile strength of different mortar admixed cubes

Table 3. Split tensile strength of different mortar admixed cylinders

Designation	Ultimate load(kN)	Tensile stress(N/mm^2)
Control	27.71	2.94
S1	27.98	2.97
S2	27.20	2.89
S3	23.09	2.45
S4	21.29	2.26
R1	29.22	3.10
R2	28.76	3.05
R3	27.20	2.89
R4	26.39	2.54
R5	25.54	2.31
RS1	29.12	3.09
RS2	26.48	2.81
RS3	24.31	2.58
RS4	24.13	2.56
RS5	22.62	2.40

split tensile strength of 2.94MPa. The replacement of cement by RHA at 10% level showed a maximum split tensile strength of 3.10MPa. Beyond 20% level, the tensile strength decreased. As observed in compressive strength values, RHA at 10% level showed the highest tensile strength values indicating the tolerable limit of replacement as 10%. The SF added mortars showed comparable tensile strength values with control mortar. For example SF at 2% level showed 2.97MPa. The combined system consisting of OPC + 10% RHA + 2% SF also showed a highest split tensile strength of 3.09MPa.

From the compressive and tensile strength results it is confirmed that the tolerable limit of replacement of RHA is found to be 10% and SF is found to be 2%. Beyond 10% RHA and 2% SF, there is a reduction in strength observed due to the delayed formation of CSH.

3.2 Durability test results

3.2.1 Density, permeable voids, and water absorption

Table 4 to Table 6 depicts the permeability and water absorption of different types of composite cement mortars. From the tables it was found that the water absorption and permeable voids for all the systems are found to be higher for all the composite systems when compared to OPC. This is due to the fact that, all the composite systems contain supplementary cementitious materials which delayed the formation of CSH gel due to delayed pozzolanic reaction. High fineness and cellular structure may increase the water absorption of the binary and ternary systems. Coefficient of water absorption also was found to be same for all the systems.

Table 4. Wet and dry weights of different types of composite cement mortars

Designation	Initial wt. (g)	Weight after immersion (g)	Weight after boiling (g)	Weight after boiling in immersion (g)
Control	282.19	289.98	291.36	155
S1	275.98	287.09	288.24	155
R1	275.97	285.58	286.69	155
RS1	253.13	265.52	271.07	155

Table 5. Permeability and water absorption of different types of composite cement mortars

Designation	Permeability/ Voids (%)	Water Absorption (%)	Absorption after immersion and boiling (%)
Control	6.76	2.82	3.25
S1	9.25	4.02	4.47
R1	8.11	3.48	3.87
RS1	20.52	6.99	9.22

Table 6. Coefficient of water absorption of different types of composite cement mortars

Designation	Dry Bulk density	Bulk density after immersion	Bulk density after immersion& boiling	Apparent density	Coefficient of water absorption
Control	2.07	2.12	2.13	2.22	2.032×10^{-6}
S1	2.07	2.15	2.16	2.28	2.540×10^{-6}
R1	2.09	2.17	2.18	2.28	3.088×10^{-6}
RS1	2.13	2.29	2.34	2.34	2.336×10^{-6}

3.2.2 Sorptivity test

Sorptivity obtained for different composite systems are plotted and represented in Fig. 5 and Fig. 6. From the figures it is found that the sorptivity is found to be lower for the RHA replaced mortar up to 25% and SF up to 6%. When compared to OPC most of the composite systems showed lower sorptivity values.

3.2.3 RCPT test

RCPT parameters like charge passed (Coulombs) measured for SF & RHA cement concretes were reported in Table 7. From the table it is observed that, OPC concretes showed 2685 coulombs. The addition of SF&RHA considerably reduced the charge passed through the mortar samples, like 2% SF, 10% RHA and 10% RHA + 2% SF added concretes showed 734, 845, 377 coulombs respectively. Pozzalonic materials like SF & RHA contains amorphous silica. These silica react with $Ca(OH)_2$ or calcium based phases like aluminates, ferrite and enhanced the CSH gel. The CSH gel considerably reduced the charge passed through SF and RHA added concretes. In the case of combined system, charge passed was found to be 7 times lower than the OPC due to the dense packing of particles.

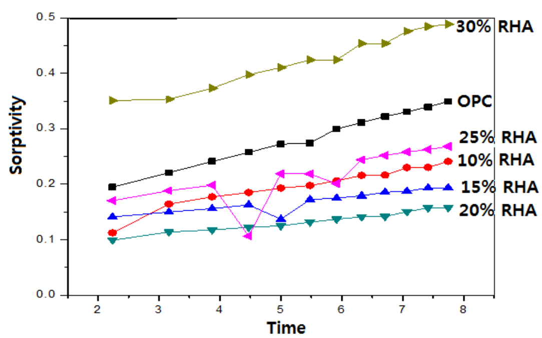

Fig. 5. Sorptivity of OPC plus RHA

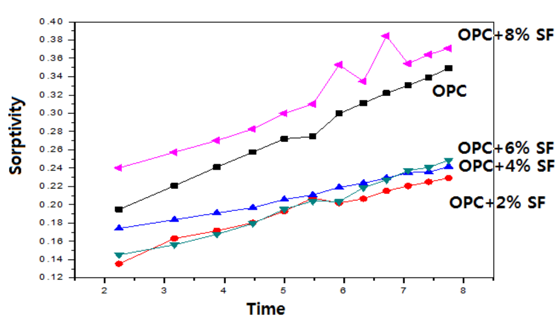

Fig. 6. Sorptivity of OPC plus SF

Table 7. Charge passed after 6 hours of RCPT test (28days)

Designation	Charge passed / Coulombs	Rating of Chloride Permeability as per ASTM C1202-09	
		Charge passing in Coulombs	Chloride permeability rating
Control	2685.89	Greater than 4000	High
S1	734.4	1001 to 2000	Low
R1	845.83	1001 to 2000	Low
RS1	377.1	100 to 1000	Very low

3.2.4 Impressed voltage test and gravimetric weight loss determination

The current versus time behaviour for different systems studied were illustrated in Figures 7 to 9. Impressed test parameters like time taken for initial crack (hours), weight loss of embedded steel and corrosion rate for OPC (control),

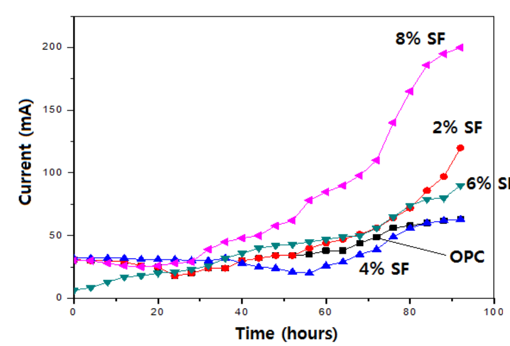

Fig. 7. Current vs Time plot obtained from OPC+SF

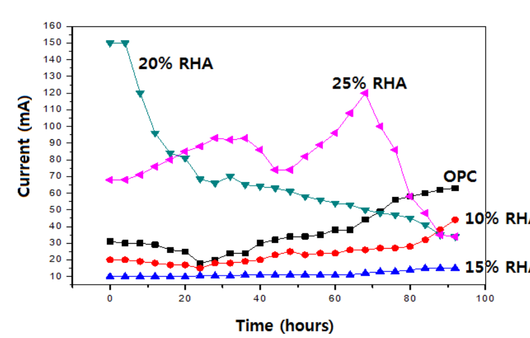

Fig. 8. Current vs. Time plot obtained from OPC+RHA

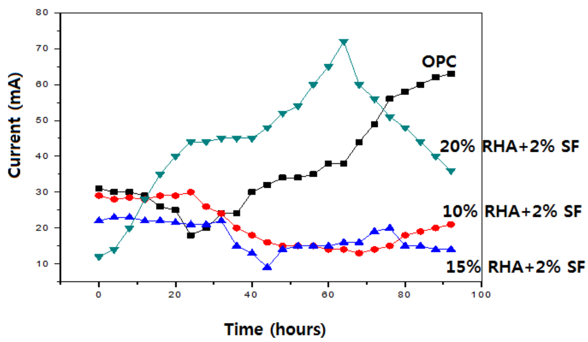

Fig. 9. Current vs. Time plot obtained from OPC+RHA+SF

Table 8. Impressed voltage test results after 28days curing

Designation	Weight loss (g)	Time to cracking (hours)	Corrosion Rate (mm/year)
Control	1.75	72	0.0079
S1	2.59	96	0.0152
S2	0.19	72	0.0021
S3	2.57	72	0.0150
S4	4.45	48	0.0392
R1	0.73	120	0.0026
R2	0.74	120	0.0027
R3	8.03	72	0.035
R4	9.44	48	0.055
RS1	0.22	120	0.0025
RS2	0.24	96	0.0043
RS3	4.31	48	0.0253

OPC+2% SF, OPC+10% RHA and OPC+2% SF+10% RHA were reported in Table 8.

From Table 8 it was found that the time taken for initial crack for OPC (control) was found to be 72 hours. OPC+2% SF+10% RHA showed 120 hours. On the other hand 10% RHA system showed 120 hours. This data clearly indicated that as observed earlier, 10% to 20% RHA system performed well. Correspondingly the weight loss data obtained for embedded steel were 0.73, 0.14, 8.03 and 9.44 g for 10% RHA, 15% RHA, 20% RHA and 25% RHA respectively. 10% RHA system only showed very low corrosion rate of 0.0026mm/year. The reactive silica present in 10% RHA increased the formation of CSH gel. With the result, very high time taken for initial crack and very low corrosion rate were obtained.

4. CONCLUSIONS

The following conclusions were drawn from the above investigation.

1. The 28 days compressive strength test results indicated that, the RHA replaced concretes showed higher or equal compressive strength values at 10% and 20%, and SF replaced concrete showed equal performance at 2 and 4% when compared to OPC. The tensile strength test results also indicated that the tolerable limit of replacement of cement by RHA was found to be 10%.
2. From the compressive and tensile strength results it is confirmed that the tolerable limit of replacement of RHA is found to be 10% and SF is found to be 2%. Beyond 10% RHA and 2% SF there is a reduction in strength observed due to the delayed formation of CSH gel.
3. Sorptivity results showed that composite systems shower lower sorptivity values when compared to OPC.
4. The RCPT test results showed that, addition of SF and RHA considerably reduced the charge passed through the mortar samples, like 2% SF, 10% RHA, and 10% RHA plus 2% SF added concretes viz. 734, 845, and 377 coulombs respectively. In the case of combined system, charge passed was found to be 7 times lower than the OPC due to the dense packing of particles.
5. The impressed voltage test results showed that 10% RHA system showed very low corrosion rate of 0.0026mm/year. The reactive silica present in 10% RHA increased the formation of CSH gel. With the result, very high time taken for initial crack and very low corrosion rate were obtained.

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