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Durability of Rice Husk Ash Concrete in Chloride Environment

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Abstract

The increasing use of supplementary cementitious materials (SCM's) has not only reduced the cost of concrete but also improved its long-term performance in adverse environments. Rice husk ash (RHA) produced after burning of rice husk (RH), being a SCM, has high pozzollani reactivity as it contains silica in amorphous and highly cellular form and form secondary gel in presence of cement in concrete. This paper highlights the durability performance of RHA blended cement concrete in NaCl environments. Cubical test specimens (100 mm) were cast from M_{28} grade concrete with cement replacement levels of 0, 10, 15, 20 and 25% by RHA. The test specimens were precured for 7 days in plain water (PW) and then exposed to NaCl solution of 5% concentrations for the curing period of 14,28,60 and 180 days. After specific curing period, the test specimens were subjected to different tests including visual examination, compressive and tensile strength, chloride content and P^H at different depth levels. RHA concrete showed significant resistance in strength loss and chloride penetration. Moreover, 10 % to 15% cement replacement level in concrete was found effective from strength and durability point of view.

Keywords: *Rice Husk Ash (RHA); Compressive Strength; Split Tensile Strength; NaCl environment; Durability.*

1 Introduction

Concrete has been recognized as infrastructural construction material all over the world long since. The main constituent of concrete is cement and its production is associated with the emission of CO_2 gases that causes greenhouse effect thereby in balancing the environmental equilibrium. The cement production is also depleting the natural resources periodically that are creating ecological strains. The increased price of construction materials including cement, now-a-days, has become a practical problem in infrastructural development throughout the globe. Also, solid waste such as industrial and agricultural waste from rural and urban areas are being generated as a result of human activities in considerable quantities of over 2500 million ton per year (Ramaswamy,2012). At present, a growing trend has been noticed towards the use and development of industrial and agricultural waste as supplementary cementitious material. The most common industrial and agricultural by products or waste such as Rice Husk Ash (RHA), ground blast furnace slag (GBFS), fly ash (FA), silica fume (SF) etc. are becoming prospective areas of research. The use of these waste not only leads to diversified binding quality of blended cement, but also to minimize the cost and negative environmental effects (Chandaprosist et al.2008).

Rice husk, one of the main agricultural wastes, is obtained from the outer covering of the rice grains during rice milling process. Around 500 million tons of paddy is produced in the world of which around 20% of RH is generated (Bhamumathidas, N. et al., 2004). The huge amount of RHA obtained after burning of RH has no such useful application and usually been dumped into water streams or land which causes pollution and contamination until it is used as mineral admixture for concrete (De Sensale,2006). Generally, mineral admixtures including RHA possess a cementitious property that improve the strength and durability of structural concrete (Ferraris et al., 2001). Proper incineration and grinding of RHA is very important in order to get good quality ash. Well incinerated and ground RHA fulfils the physical and chemical composition of mineral admixture. Pozzalanic quality of RHA depends on different factors including silica content, crystallization phase, size, surface area of RHA particles etc. The amorphous silica and large surface area can be produced by incinerating of RHA at controlled specific temperature (Metha, 1995).

RHA is an excellent supplementary cementitious materials based on both pozzalonic and fillers effects. RHA contains silica in amorphous and highly cellular form with 50-1000 m^2/g surface area. Amorphous RHA dominates the chemical or pozzalonic effect and its crystalline form dominates the physical or filler effect (Siddika, A. et al., 2021). So, the use of RHA with cement improves workability, stability, reduces heat evolution, thermal cracking and plastic shrinkage. This improves strength, permeability, durability by strengthening the transition zone, modifying pore connectivity, blocking the large voids in the hardened cement matrix after pozzalonic reactions. RHA reduces alkali, aggregate reaction expansion, refine pore structure and minimizes the diffusion of alkaline ions to aggregate surface due to micro porous structure (Zareei, SA., et al.,2017). Many developing countries generate huge volume of agro waste that causes severe environmental pollution. Use of properly burnt RHA improves the strength and durability of mortar and concrete and also reduces the environmental pollution related to disposal of these waste materials (De Sansale,2006, Siddika, A., et al., 2021).

A lot of investigations have been carried out on the use of RHA as partial replacement of cement in making concrete by several researchers including Jaya Sanker et al. (2010); Nargate et al., (2012); Marthong et al., (2012); Ramaswamy, (2012); Alireza et al., (2010); Abalaka (2013); Rao, PP., et al., (2014); Zareei. SA et al., (2017); Siddika, A. et al., (2021); and others. Cement replacement by RHA in concrete are reported to vary from 0 to 40% in existing literature. Cement replacement upto 20% is recommended by most of the researchers from workability, strength, durability and economic point of view.The present study investigates the strength and durability performances RHA blended concrete made with different percentage of RHA with cement in an NaCl environment upto a period of 6 months.

2 Experimental Program:

To comply with program objectives, the program was designed with different materials and method as discussed below

2.1 Cement: Ordinary port land cement (OPC) conforming to ASTM C150 was collected for making concrete. Table 1 shows the physical properties and chemical composition of cement.

2.2 Rice Husk Ash (RHA): RHA was collected from local rice milling industry. It was then grounded to have adequate fineness using loss angel machine. Table 1 also shows the properties of RHA.

2.3 Aggregates: Locally available coarse natural sand (Sylhet Sand) having fineness modulus (FM) of 2.58 and specific gravity (SG) of 2.61 was used as fine aggregate (FA), coarse aggregate (C.A) was comprised of well graded stone chips having 20 mm normal size and specific gravity of 2.78 for concrete mix.

2.4 Concrete Mix: M_{28} grade concrete was designed after several laboratory trials. The different mixes were obtained by partial replacement of cement by RHA (i.e. 0%, 10%, 15%, 20% and 25% by weight) keeping the other components i.e. FA, CA and water fixed. The control concrete (i.e. 0% RHA content) was prepared to compare the properties of RHA blended concrete in different environments. Table 2 shows the details of concrete mix design components.

Table 2. Mix Proportion of RHA Blended Concretes

Mix No.	Cement: RHA	Quantities in kg/m^3					
		Cement	RHA	F.A.	C.A	Water	w/c
01	100:0	435	0.0	545	1150	218	0.50
02	90:10	391.5	43.5	545	1150	218	
03	85:15	369.7	65.5	545	1150	218	
04	80:20	348.0	87.0	545	1150	218	
05	75:25	326.2	108.8	545	1150	218	

2.5 Casting of test specimens: For each type of mix, OPC, RHA, CA and FA were mixed thoroughly according to mix proportion. Water was added after one minutes of dry mixing and the mixture contents were mixed properly for the next three minutes. 100 mm cubical steel mold specimens, prepared with oily surface, were filled up with concrete in two equal layers after compaction in each layer. Compaction was done manually using a circular tamping rod (0.45 m long, 16 mm diameter) with 25 blows per layer. The finished specimens were kept at room temperature and demolded after 24 hours of casting. The specimen was then precured for 7 days in PW and then immersed in NaCl environments. Around 200 nos specimen was cast for PW and NaCl environment.

2.6 Exposure Environments: After pre-curing the specimens were immersed in PW as well as NaCl environment for the exposure period of 14,28,60,90 and 180 days. NaCl environment was created by mixing 5% NaCl salts in plain water. The enhanced salt concentration of the environment was to induce accelerated effect within short time span.

2.7 Test Conducted: various tests including visual examination, compressive and tensile strength, chloride content and P^H at different depth levels etc. were conducted after specific age of curing in PW and in NaCl environments. Three identical specimens were tested for any parameter for each concrete mix and average of test results were taken to represent a particular value. The rate of loading was kept constant and loads were applied to other than casting faces. BS1881-166:1983 and IS 5816:1999 specifications were followed for compressive and split tensile strength respectively. Powdered concrete sample were collected from different depth levels of the specimens (1 mm, 15mm and 25mm) using masonry drill. Volhard method using back titration with $AgNO_3$ solution was used to determine chloride content (Clask, GL,1949). To determine PH level, the powdered sample was mixed with distilled water for at least 2hr with occasional stirring. The suspension was then filtered through a filter paper and PH was determined using a calibrated PH meter.

3.0 Results and Discussion: The tests were analyzed and presented in graphical form for the ease of interpretation and are discussed as follows.

3.1 Visual Examination: The surface of the exposed specimen were inspected visually and no sign of cracks or surface damages were noticed. However, some shorts of color changes from off-white to brown were noticed for specimens cured in NaCl environments. For RHA concretes, such changes were reported to as minimum (Ref: Figure 1.).

Figure 1. From Left (a) specimens exposed to sodium chloride environment and (b) Specimen exposed to plain water

3.2 Compressive Strength: The compressive strength of the control as well as RHA concrete specimens exposed to PW and NaCl environments for different curing ages are shown in Figure 2. and Figure 3. From figs. it is seen that for control concrete in PW, the strength development occurs in usual way that is the rate of gain in strength is higher in early ages and afterwards the rate decreases. In NaCl environment, the strength increases relatively higher rate in early ages i.e., upto 60 days and then start decreasing. For RHA concrete, the rate of strength development at early ages is relatively lower but significant at later ages. Due to the formation of secondary gel in presence of RHA is the reason for later strength development. Upto 15% cement replacement, the strength development of RHA concrete is found more significant, even greater than control concrete. Overall study results show that RHA concrete of 15% cement replacement attain around 2-3% higher strength than control concrete. In NaCl environment, after 180 days curing, the control concrete showed around 17% strength loss. Whereas RHA concrete upto 15% cement replacement, showed 3-5 % strength loss as compared to PW cured control concrete. It clearly indicates the durable nature of RHA concrete in aggressive environment.

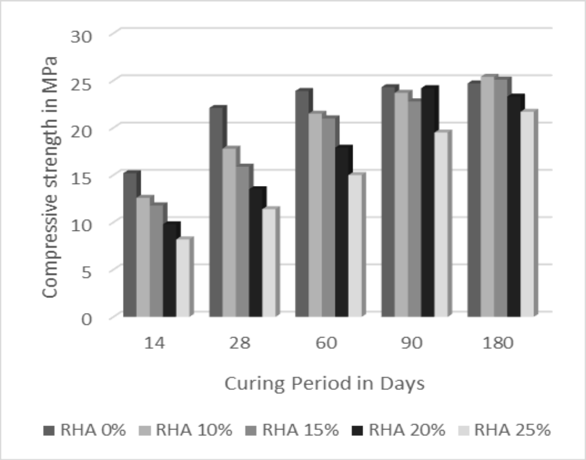

Figure 2. Compressive Strength of concretes PW Environment

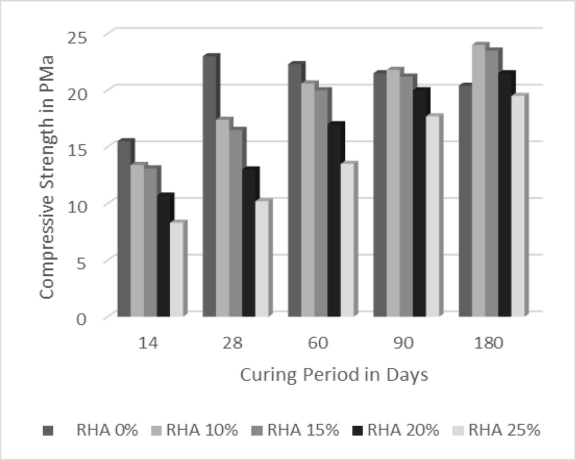

Figure 3. Compressive Strength of Concretes in NaCl Environment

3.3 Split Tensile Strength

The split tensile strength of control and RHA concrete specimens exposed to PW and NaCl environment for different curing ages are shown in Figure 4 to Figure 5. The split tensile strength development of control and RHA concrete is observed to occur in similar trend as that of compressive strength in PW as well as NaCl environment. The strength development of RHA concrete was lower at early ages and enhanced at later ages.For split tensile strength also, cement replacement by RHA upto 15% showed significant strength development in PW as well as NaCl environment. From the strength data, it is seen that RHA concrete upto 15% RHA content, attain around 1% higher strength that control concrete in PW after 180 days of curing. In NaCl environment, control concrete loses around 20% strength as compared to PW cured strength. On the other hand, concrete with 10 to 15% cement replacement by RHA shows 5 to 10 % reduction in strength as compared to PW cured strength.

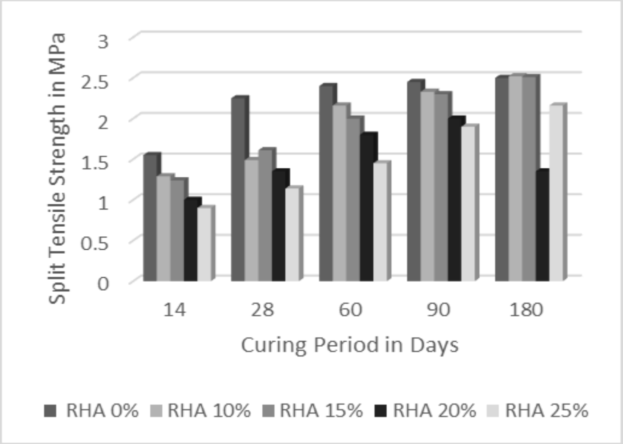

Figure 4. Split Tensile Strength of different RHA Concretes in Plain Water

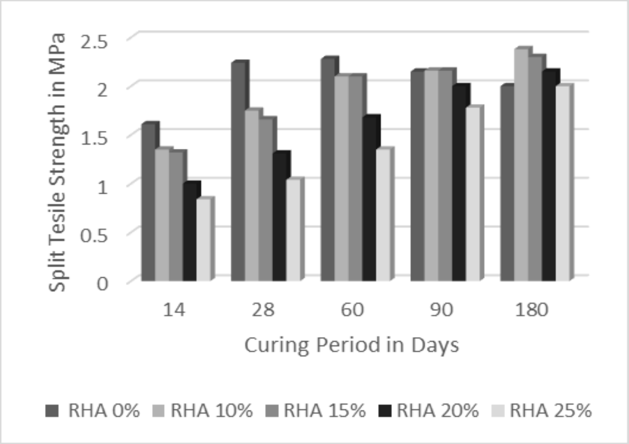

Figure 5. Split Tensile Strength of different RHA Concretes in NaCl Environment

3.4 Chloride Penetration

The chloride penetration at different depth levels of both control and RHA concrete with varying ash content are shown in Figure 6. Chloride penetration has been measured at surface (1 mm), 15 mm and 25 mm depth levels to assess the rate of chloride penetration within the concrete. From Fig. it is observed that the chloride percent vary in the range of 0.113 to 0.136 %, 0.028 to 0.135 % and 0.019 to 0.067 % respectively at surface (1 mm), 15 mm and 25 mm depth level respectively. As usual, the chloride values decrease with the increase of depth levels for all types of concrete. At any depth level, chloride content values are found higher in case of control concrete than the RHA concrete. This is due to impermeable nature of RHA concrete in which additional CSH gel is developed as a result of secondary hydration reactions. Again 10% & 15% RHA concrete showed minimum chloride penetration than other RHA concretes. Considering 15 mm depth level, 10 to 15 % RHA concrete showed around 25 to 45 % Lower chloride penetration than the control concrete at 180 days exposure.

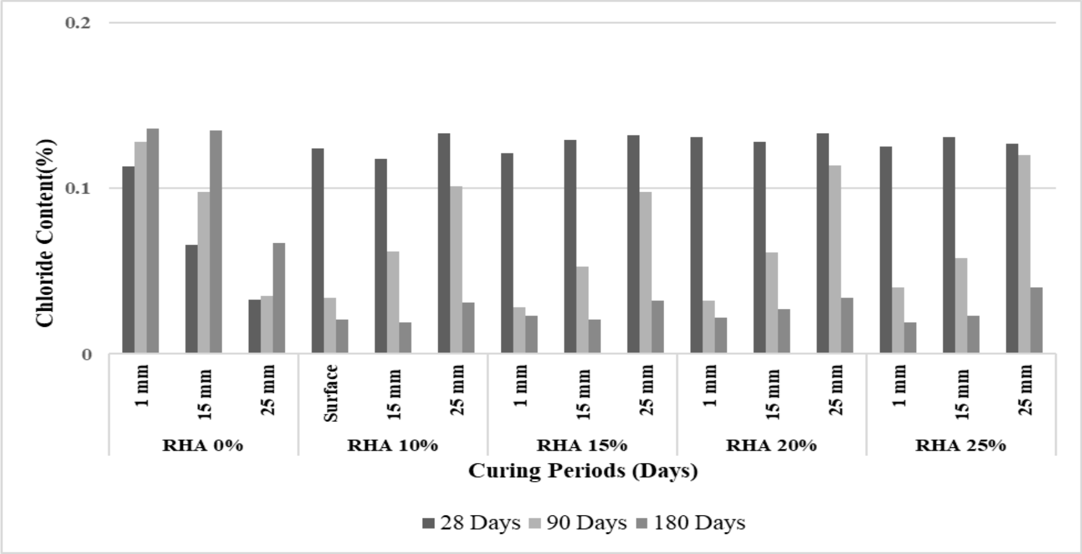

Figure 6. Chloride Content (%) at different depth levels of RHA concretes in NaCl Environment.

3.5 p^{H} Values

The p^{H} values of concrete at different depth levels of control and RHA concretes exposed to NaCl environment are shown Figure 7. p^{H} level at different depths were measured to assess the alkaline conditions of concrete under the action of salt environment. From practical consideration, p^{H} of concrete was measured only at 90- and 180-days exposure. The pH value of hardened concrete generally varies from 12-13. In the study, the observe p^{H} values were seen to vary from 10.0 to 12.40. As usual, the p^{H} of surface of specimen were minimum and it increases with depths in PW as well as in NaCl environments. However, the changes in p^{H} values are marginal. Again, at any depth levels, p^{H} values for 10 to 15% RHA concrete are relatively higher as compared to control concrete. It may be due to lower penetration of chloride in RHA concrete. The chloride ions form Friedel salts which is expansive and leachable as well. However, all the observed values are well above the limiting value (≥9.5) for initiation for rebar corrosion. Thus, it is seen that RHA concretes have more capability to preserve alkalinity in concrete than the identical control concrete.

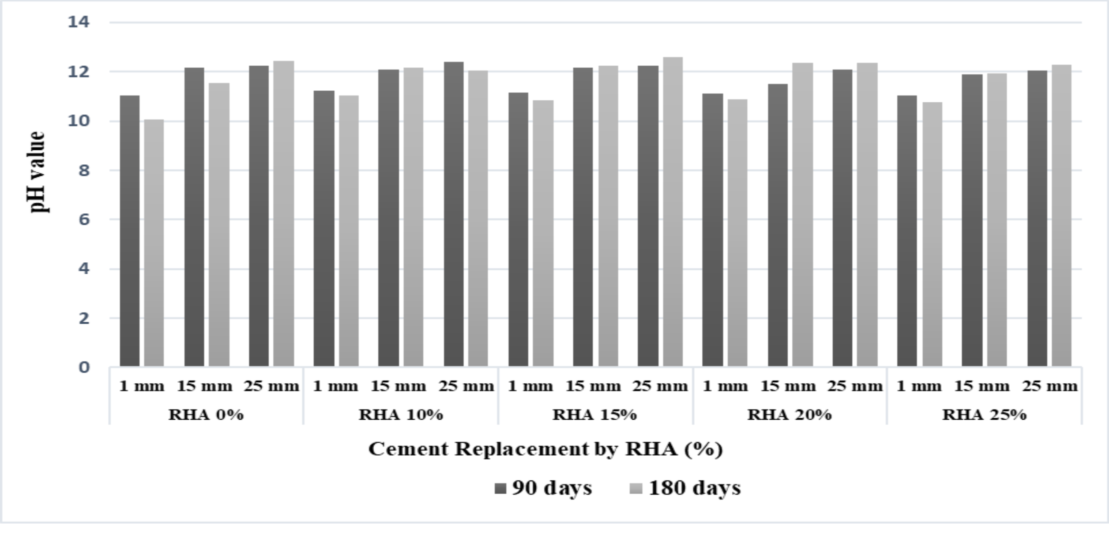

Figure 7. p^H values of RHA concretes at different depth levels in NaCl Environment.

4.0 Conclusion

The above-mentioned program presents a durability study concerning the performance of RHA concrete with different RHA contents in NaCl environment over a time span of 6 months. The duration is too short to assess the behavior of concrete in aggressive environment. However, based on the limited numbers of variables and curing exposure periods, the following conclusions can be drawn these form.

(i) Both control and RHA concretes showed change in color from off-white to brown due to salt action.
(ii) The gain in strength of RHA concrete is found lower at early ages but faster at later in comparison to no RHA concrete.
(iii)In PW, concrete upto 15% RHA content showed 2.0 to 3.0 % higher compressive strength and 0.4 to 0.8% higher split tensile strength than control concrete.
(iv)Both control and RHA concrete lost strength after 180 days in NaCl environment, the maximum compressive and tensile strength losses were observed as about 17 and 20% respectively for control concrete. The corresponding losses for 10-15% RHA concrete vary from 3.0 to 10.0 respectively.
(v) The chloride penetration in RHA concrete is found to be lowered than that of control concrete. At 15 mm depth, 10 to 15% RHA concrete showed around 25 to 45 % lower chloride penetration than control concrete.
(vi) At any depth level RHA concrete showed higher p^H levels than control concrete. However, the observed p^H values were above the limiting value for initiation of rebar corrosion.
(vii) Among the concrete mixes, 10 to 15% cement replacement with RHA is found optimum from both strength, durability and economic points of view.

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