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Performance of rice husk ash concrete in NaCl environment

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Abstract

Rice Husk Ash (RHA) concrete possesses a number of good qualities that make it structurally and environmentally sound. It helps in reducing greenhouse gases as well as cost of concrete. RHA produced after burning of Rice Husks (RH) has high reactivity and pozzolanic property. RHA contains silica in amorphous and highly cellular form and its presence with cement improves both the fresh and hardened concrete properties. This paper presents a study on the strength performance of RHA blended concrete in plain water (PW) and NaCl environment.100 mm cubical specimen for compressive and split tensile strength test were cast from M28 grade concrete. Five different replacement levels for cement by RHA (0%,10%,15%, 20% and 25%) were used to make blended concrete specimens and were precured for 7 days in plain PW before exposed to NaCl environment of 5% concentration over the periods of 14,28,60 and 180 days. After specific exposure period, the specimens were tested for visual examination, compressive and split tensile strength. Chloride contents and PH values at different depth levels of the specimens were measured to observe the transport properties and alkaline conditions of concrete. RHA concretes showed significant resistance against strength deterioration as well as chloride penetration in concrete. Among the various RHA concretes, 10 to 15% cement replacement level is found effective from strength and durability point of view.

Keywords: Rice husk ash (RHA), compressive strength, split tensile strength, NaCl environment, chloride penetration, alkalinity.

1. Introduction

The demand for structural concrete as infrastructural material in increasing day by day with the increase of population in the world. The cement production depleting the natural resources periodically are creating ecological strains. On the other hand, human activities produce solid wastes such as industrial and agricultural wastes from rural and urban areas in considerable quantities of over 2500 million tons per year (Ramasamy, 2012). The increased price of construction materials including cement has become a major problem in infrastructural development throughout the world. The cement production is also with associated with a lot of CO_2 emission causing greenhouse effect. Nowadays, there has been a growing trend towards the use and development of industrial and agricultural wastes as supplementary cementitious materials. The common agricultural and industrial by products or wastes such as rice husk ash (RHA), ground blast furnace slag (GBFS), fly ash (FA) etc. are becoming active areas of research as its use not only leads to diversified product quality of blended cement, but also leads to reduction in cost and negative environmental effects (Chindaprasist et al., 2008).

Rice husk is one of the main agricultural residues obtained from the outer covering of rice grains during milling process. It constitutes around 20% of the 500 million tons of paddy produced in the world (Bhamumathidas, N. et al., 2004). The RHA had no useful applications and usually been dumped into water streams and caused pollution and contamination until it was known to be a useful mineral admixture for concrete (Sensale, 2006). Generally, mineral admixtures including RHA have a favorable influence on the strength and durability of concrete (Ferraris et al., 2001). Proper incineration and grinding method are required for burning and grinding of rice husk in order to obtain good quality ash. Properly burnt RHA fulfils the physical and chemical composition of mineral admixture. Pozzolanic activity of RHA depends on (i) silica content, (ii) silica crystallization phase and (iii) size and surface area of RHA particles having amorphous silica and large surface area can be produced by combustion of rice husk (RH) at controlled temperature (Metha, 1995). Due to both the filler and pozzolanic effects, RHA is an excellent supplementary cementitious material. Amorphous RHA is dominating the chemical or pozzolanic effect and physical or filler effect is dominated due to crystalline form of RHA (Siddika, A. et al., 2021).

Many developing countries produce large quantities agro waste which cause severe pollution to the environment. Using of RHA in cement improves the strength and durability of concrete and mortar (Sansale,2006). Use of RHA increase not only the strength or durability of concrete but also reduce environmental pollution related to the disposal of these waste materials (Siddika, A. et al., 2021). RHA contains silica in amorphous and highly cellular form with 50-1000 m^2/g surface area. So, use of RHA with cement improves workability and stability, reduces heat evaluation, thermal cracking and plastic shrinkage. This increases strength, impermeability and durability by strengthening transition zone, modifying the pore-structure, blocking the large voids in the hydrated cement paste through pozzolanic reaction. RHA minimizes alkali-aggregate reaction, reduces expansion, refine pore structures and hinders diffusion of alkaline ions to the surface of aggregate by micro porous structure (Zareei, SA. et al., 2017). Study on the use of RHA as cementitious materials has been reported by Jayasankor et al., (2010), Nargale et al., (2012), Marthong et al., (2012), Ramasamy (2012), Alireza et al., (2010), Chindarprasirt et al., (2008), Chatverra et al., (2009), Saraswathy et al., (2007), Abalaka (2013), Rao, PP. et al., (2014) and others. Replacement of RHA with cement in concrete are reported to vary from 0 to 40%.

Most of the researcher recommended for upto 20% replacement level as effective from workability, strength and economic point of view. Also review of literature reveals that much more information on the use of RHA in concrete are based on its physical and mechanical properties in non-corrosive environments. Limited studies have been conducted on the RHA blended concrete in adverse environment. This study investigates the effect of partial replacement of cement with different percentages of RHA on strength development of RHA blended concrete in NaCl environment in order to observe its durable performance in adverse environment.

2. Materials and methods

2.1 Cement

Ordinary Portland cement (OPC) meeting the requirements of ASTM C150 was used as binding material. The physical and Chemical properties of the cement is given in Table 1.

2.2 Rice Husk Ash (RHA)

The RHA was collected from local rice milling industry as residual material. The RHA materials were subjected to grounding using a loss Angel machine to have adequate fineness. The physical and chemical properties of RHA is shown in Table 1.

Table1
Physical and chemical properties of OPC & RHA

Relevant Properties	OPC	RHA
Physical	3.10	2.06
Fineness (Blaine, cm^2/gm)	4000	6000
Setting times(mins)		
Initial	145	
Final	275	
Compressive Strength (MPa)		
3 day	15.3	----------
7 day	24.8	---------
28 day	35.2	---------
Chemical (%)		
SiO_2	21.20	87.2
Al_2O_3	4.65	0.15
Fe_2O_3	2.27	0.16
CaO	63.55	0.58
MgO	3.27	0.36
MnO	-------	-----
Na_2O	0.11	1.11
K_2O	1.04	3.60
SO_3	2.19	0.32
LOI	2.30	6.58

2.3 Aggregates

Locally available natural sand (Sylhet Sand) with particle smaller than 0.5 mm, fineness modulus of 2.58 and specific gravity of 2.61 was used as fine aggregate. Well graded crushed stone chips with nominal size of 20 mm and specific gravity of 2.78 was used as coarse aggregate in concrete mix.

2.4 Mix proportions

A particular grade of concrete (M28) was selected after laboratory trials. ACI mix design procedure was followed for concrete mix proportioning. Various mixes were prepared by replacing 0%, 10%, 15%, 20% and 25% of cement (by weight) with RHA keeping the other components i.e., fine and coarse aggregate fixed. 0% cement replacement i.e., OPC concrete represent the control concrete. The details of the mix design components are given in Table 2.

2.5 Preparation of test specimens

The required amount of Portland cement, rice husk ash and fine aggregate were mix thoroughly according to the mix proportion. After one minute of dry mixing, water was added and the contents in the mixture were thoroughly mixed for three minutes. The mixture was then poured to make the test specimens. 100 mm x 100 mm x 100 mm cube specimens were cast after compaction in two equal layers. Each layer was compacted manually using a circular temping rod of 0.45 m long, 16 mm diameter with 25 blows. The specimens were demoulded after 24 hours of casting. All the specimens were precured for 7 days in plain water before immersion in NaCl environments. A total 500 nos. of specimens were cast with 250 nos. for plain water 250 nos. for NaCl environment.

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	
02	90:10	391.5	43.5	545	1150	218	
03	85:15	369.7	65.5	545	1150	218	0.50
04	80:20	348.0	87.0	545	1150	218	
05	75:25	326.2	108.8	545	1150	218	

2.6 Exposure environments

After 7 days precuring in PW, the specimens were exposed to PW as well as NaCl environment for the periods of 14, 28, 60, 90 and 180 days. NaCl environment was created by mixing 5% NaCl salts in PW. The enhanced salt concentration was used to have accelerated effect of salt environment on concrete specimens within limited time period.

2.7 Test conducted

Different tests including visual examination, strength test (compressive and split tensile strength), Chloride penetration, P^H value etc. were carried out at different ages of curing i.e., 14,28,60,90 and 180 days in plain water as well as in NaCl environment. For each mix combination, three identical specimens were tested and average of the test results were taken as the representative data. For strength test, the specimens were taken in SSD condition after wiping out the surface moisture. Loads were applied at uniform rate to other than casting faces. The compressive and split tensile strength were determined according to BS 1881-166:1983 and IS 5816:1999 respectively. For chloride content and p^H level test, concrete powder was collected from different depth levels of the specimens with the help of masonry drill. Drilled concrete powder was then grounded to pass through No. 200 sieve and then kept in individual small plastic bag in sealed condition to avoid carbonation. The chloride contents at any depth of the specimen were determined using back titration with $AgNO_3$ solution according to Volhard method (Clark, G.L.,1949). The powdered concrete sample were also used to determine the P^H level after mixing it with distilled water with occasional stirring. After specific time, the suspension was filtered using a filter paper. p^H was then determined using a P^H meter.

3. Results and discussion

3.1 Visual examination

Visual Examination of the specimens' exterior surfaces show no sign of cracks or surface damage. However, the specimens exposed to NaCl solution showed color change from off-white to brown as shown in Figure 3.1. The color change was minimum for RHA concrete. The specimens in PW showed practically no change in color. The change in color in the exposed surface in NaCl environment may be primarily due to salt deposition. The textures inside the specimen were found in original color. For large exposure periods, a relatively higher degree of saturation was observed indication the deeper penetration of salt water.

Fig. 3.1. From left, specimens exposed to sodium chloride environment and specimens 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 3.2 and 3.3 From figures. 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. The early strength increase may be due to accelerated effect of chloride ions and the decrease at later periods is due to the formation of Friedel salts which is expansive and leachable in nature.

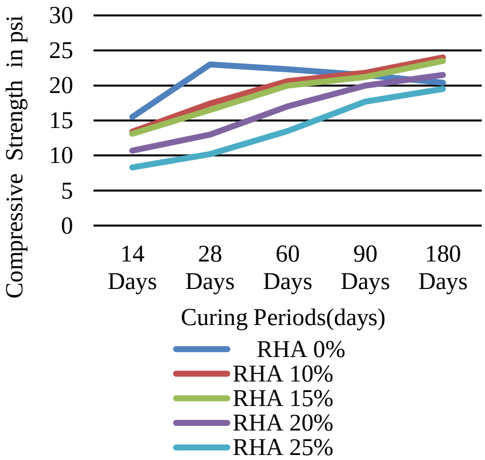

Fig. 3.2. Compressive strength of different RHA concretes in PW environment.

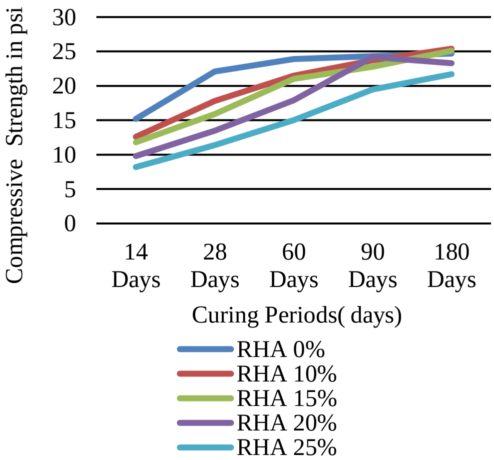

Fig. 3.3. Compressive strength of different RHA concretes in NaCl environment.

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. In NaCl environment, the strength of RHA concrete also decreases at later ages but rate of decrease is lower as compared to control concrete. However, for higher RHA content concrete, higher strength loses occur at later ages. 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.

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 Figures 3.4 to 3.5. 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.

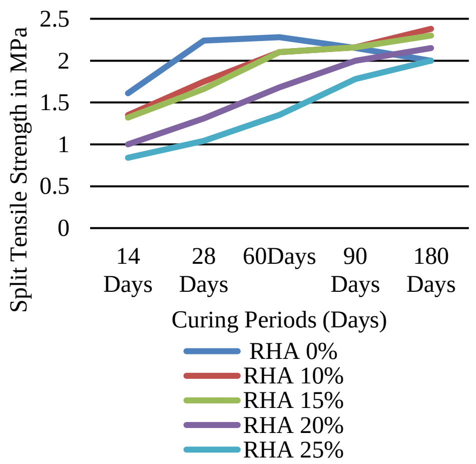

Fig. 3.4. Split tensile strength of different RHA concretes in plain water.

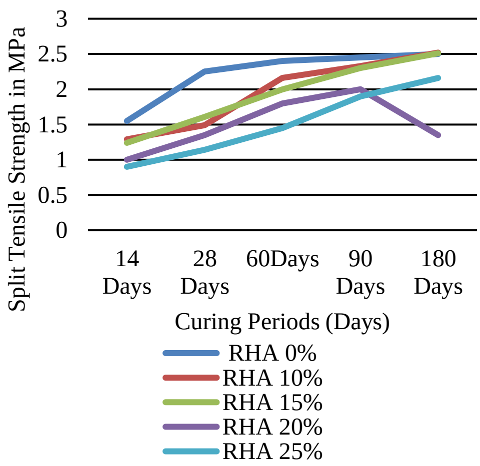

Fig. 3.5. Split tensile strength of different RHA concretes in NaCl environment.

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 3.6. 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 figure 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.

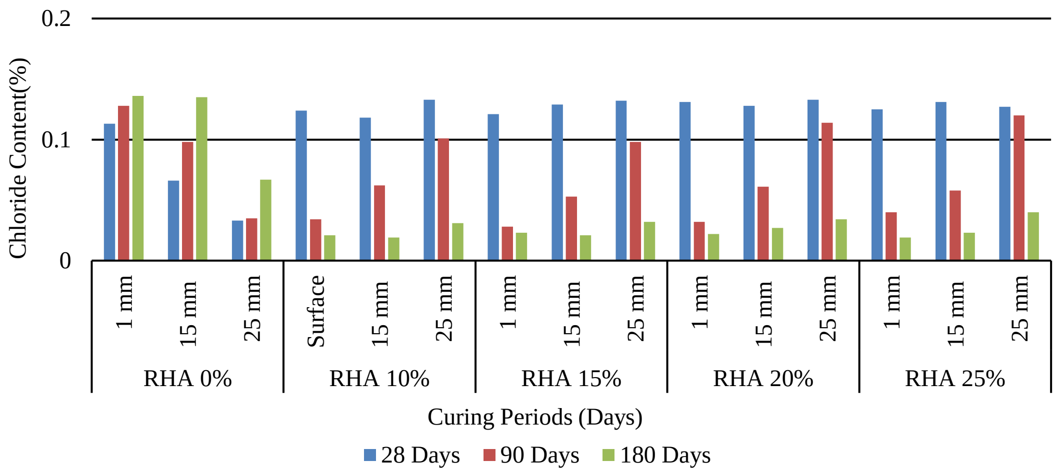

Fig. 3.6. Chloride content (%) at different depth levels of RHA concretes in NaCl environment.

3.5 p^H values

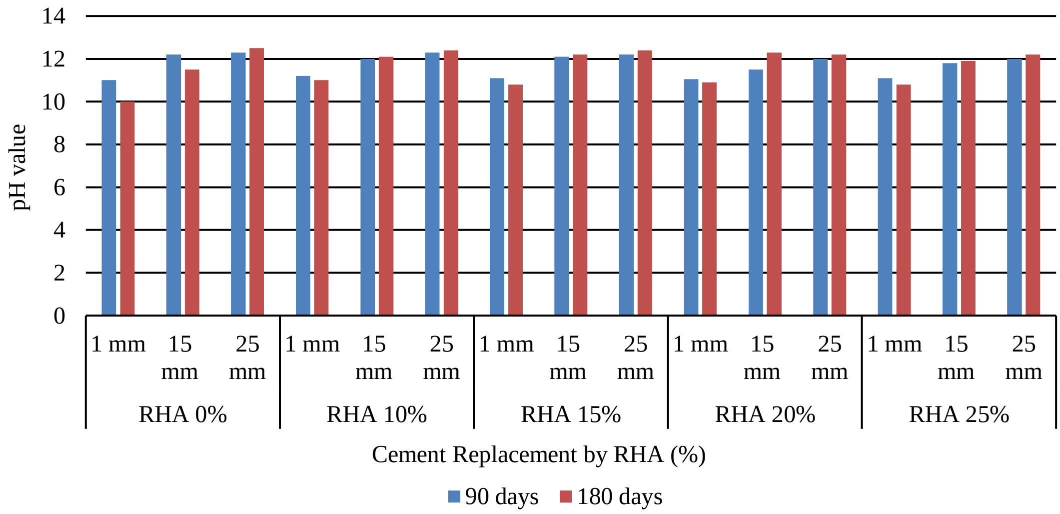

Fig. 3.7. p^H values of RHA concretes at different depth levels in NaCl environment.

The p^H values of concrete at different depth levels of control and RHA concretes exposed to NaCl environment are shown Figure 3.7. 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.

4. Conclusions

The present investigation presents a durability study regarding the performance of RHA concrete with different RHA contents in NaCl environment over a period of 6 months. The time frame is too short to predict the behavior of concrete in aggressive environment. However, based on the limited numbers of variables and exposure periods, the following conclusions are drawn:

- Both control and RHA concretes showed change in color from off-white to brown due to salt action.
- The strength development of RHA concrete is lower at early ages but faster at later ages as compared to control concrete.
- 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.
- In NaCl environment, both control and RHA concrete losses strength after 180 days. The maximum compressive and tensile strength losses were recorded as about 17 and 20% respectively for control concrete. The corresponding strength losses for 10-15% RHA concrete vary from 3.0 to 10.0 respectively.
- The chloride penetration in RHA concrete is observed to be lowered than that of control concrete. At 15 mm depth, 10 to 15% RHA concrete showed 25 to 45 % lower chloride penetration than control concrete.
- RHA concrete showed higher p^H levels than control concrete at any depth level. All the observed p^H values were above the limiting value for initiation of rebar corrosion.
- 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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