Effects of Sodium Chloride Solutions on Compressive Strength Development of Concrete Containing Rice Husk Ash

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Abstract

The study investigated the effects of sodium chloride (NaCl) solutions as curing medium at concentrations of 5% and 10% on compressive strength of concrete cubes containing 5% rice husk ash (RHA). Concrete cubes containing 5% RHA in NaCl solutions show early compressive strength increase at 3 and 7 days over control cubes; at 28 days concrete cubes containing 5% RHA cured in NaCl solutions recorded higher strength loss compared to control cubes.

Keywords: Sodium chloride, concrete, compressive strength.

Introduction

Sodium chloride or rock salt could be used as a deicing agent to melt ice at temperatures below 20^{o}F; it has a characteristic sharp taste and is readily soluble in water (encyclopedia.com, 2010). It has been known to be relatively benign on concrete compared to other salts (Cody et al, 1996). Sodium chloride is an ionic compound made up of equal numbers of positively charged sodium and negatively charged chloride ions (peterschemical.com, 2010). Early studies by Henry and Griffin (1964) on sodium chloride in mixing water reported it to cause increase in compressive strength of concrete at concentration of 25gm per 1kg of solution without significant corrosion of mild steel, with accompanying reduction in water vapor transmission. However, NaCl is known to have erratic effects in concrete and has been reported to cause set acceleration in some cements and retarding effects in others (Mattus and Gilliam, 1994). The works of Shi et al. (2011) on deicers containing NaCl indicate that NaCl causes substantial compressive strength loss in concrete. Though sea water NaCl content of about 3.5% produces the most corrosive chloride salt solution that can be obtained with a corrosion rate of 1.74mm/year (corrosion-doctors.org, 2010), NaCl solutions of 5% concentration have been used to investigate durability properties of concrete containing RHA in the laboratory (Anwar et al, 2000). The use of RHA in concrete could enhance known properties of concrete (Givi, *et al.*, 2010; Kartini *et al.*, 2010; Reddy and Alvarez, 2006); e.g. 10% RHA has been shown to reduce chloride ion penetration in concrete by a factor of three compared to control cubes at 28 days (Zhang and Malhotra, 1996).

RHA is a pozzolana that is used globally for the production of high performance concrete structures. It contains mainly reactive amorphous silica that reacts with calcium hydroxide liberated by cement hydration in concrete matrix to produce dense calcium silicate hydrates (CSH) that is mainly responsible for improved concrete performance (Giannotti de Silva *et al.*, 2008; Reddy and Alvarez 2006; Rodriguez de Sensale, 2006; Zhang and Malhotra, 1996). The work of Qijun, *et al.* (1999) shows that amorphous silica in RHA reacts with Ca^{2+} and OH^- ions in hydrating cement to form more CSH gel and less portlandite that leads to compressive strength increase in concrete containing RHA compared to concrete without RHA.

A detailed investigation of RHA composite concrete in saline solutions is scarce and the purpose of this laboratory study is to determine the effect of sodium chloride solutions on compressive strength properties of concrete containing RHA to determine the suitability of this type of concrete in saline environment that could be of interest in coastal areas.

Materials and Method

The RHA used for this study was produced using a charcoal fired incinerator from rice husk sourced from a local rice mill in Minna town. The RHA was milled before samples were taken for analysis. For the quantitative determination of the mineral phases of the RHA, ground samples were subjected to X-ray diffraction (XRD) analysis. The RHA samples were sprinkled on carbon stubs and analyzed using Quanta 600F FEG Scanning Electron Microscope (SEM) equipped with two Bruker detectors and operated at accelerating voltage of 20kV, ESEM vacuum mode and Back Scatter Electron (BSE) imaging. The analysis shows that the RHA is composed of siliceous particles and trace amounts of phosphates, carbonate and iron oxide. The microstructure of the RHA by BSE imaging in Plate1 shows the porous structure of the milled RHA used in this work. Carbonates identified in the RHA occur as fine grained particles (approximately 5µm) and based on energy dispersive X-ray spectroscopy (EDS) and XRD analysis, the carbonate was identified as fairchildite ($K_2Ca\ (CO_3)$). Laser diffraction was used for the particle size analysis. Fifty percent of the milled RHA has particles ≤46.451µm. The results of the analysis of the RHA are given in tables 1 and 2. The sodium chloride used has a minimum assay of 99.9% after ignition.

The sand used was natural river bed quartzite and the coarse aggregate was crushed granite of 20mm maximum size. The fine and coarse aggregates grading are given in figures 1 and 2. All the aggregates were sourced from Minna town. Physical properties of the aggregates are given in Table 3. The cement used was a commercial brand of ordinary Portland cement (OPC). The concrete mix proportions are given in Table 4.

Table 1: Physical properties and mineral composition of RHA.

Specific surface	Loss of ignition (LOI)		Amorphous (opal- SiO_2nH_2O)	Crystalline (cristobalite SiO_2)	Quartz (SiO_2)	Langbeinite $KBaFe_2(PO_4)_3$)	Fairchild ($K_2Ca(CO_3)$) and Phosphates in trace amounts
	800°C (6 min.)	1050°C (2 hrs)					
235m²/kg	0.77%	3.88%	90%	1%	6%	2%	1%

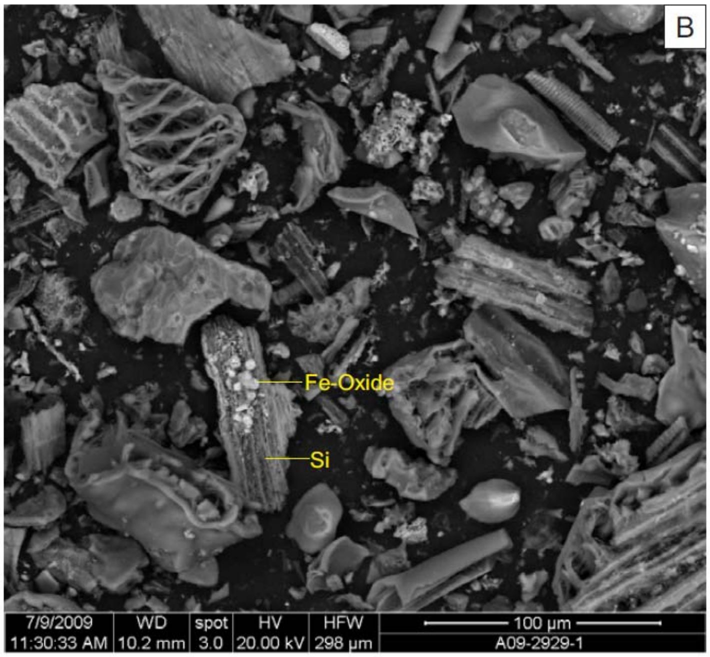

Plate I: Microstructure of the milled RHA (×1000).

Table 2: RHA composition by mass.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
95.41%	0.00%	082%	0.00%	1.24%	0.07%	1.65%
Na_2O	**Mn_2O_3**	**P_2O_5**	**TiO_2**	**Cl-**		
0.22%	0.19%	3.97%	0.03%	0%		

Table 3: Physical characteristics of fine and coarse aggregates.

		Bulk density	
	Specific gravity	Un-compacted	Compacted
Fine aggregates	2.6	1,417kg/m^3	1,533kg/m^3
Coarse aggregates	2.7	1,261kg/m^3	1,483kg/m^3

Table 4. Concrete mix proportions.

Cement content	Sand	Coarse aggregates	Free w/c ratio
425kg/m^3	446kg/m^3	1,419kg/m^3	0.40

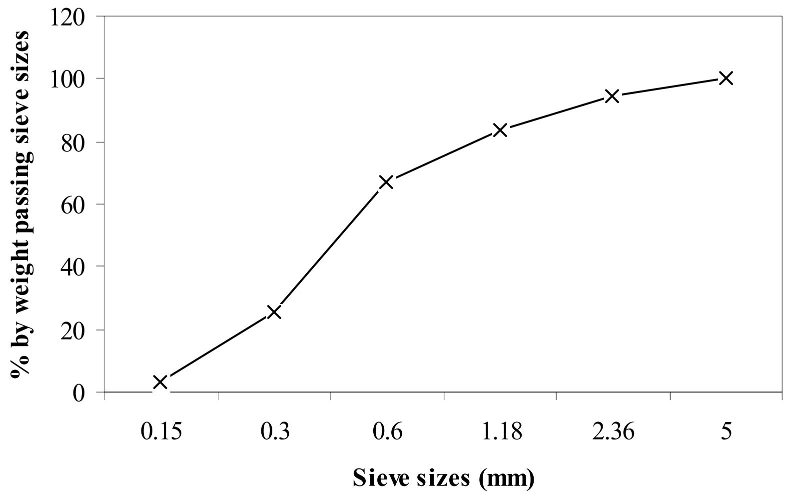

Figure 1: Particle size distribution of fine aggregates.

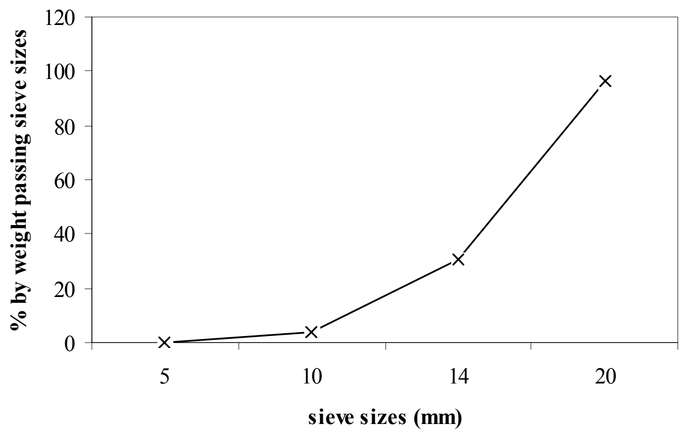

Figure 2: Particle size distribution of coarse aggregates.

The study was carried out in two stages using 100mm cubes; the first stage was to determine the RHA content required to produce maximum compressive strength increase in concrete at 28 days at a constant water/binder (w/b) ratio of 0.40. The concrete for the first stage was manually mixed and compacted. The results of this are shown in Table 5.

The second stage was to determine the effects of NaCl on concrete cubes at concentrations of 5% and 10% by weight of water at RHA content of 5% determined from the first stage at hydration periods of 3, 7, 14, 21, and 28 days. The same w/b (b=cement plus RHA) ratio of 0.40 used for the first stage was used for the concrete cubes. The concrete was mixed for 2.5 minutes using a drum mixer and vibrated for 3 minutes in two 50mm layers using a table vibrator. After 24 hours in 100mm steel moulds, the cubes were then cured in NaCl solutions at 21^{o}C for 3, 7, 14, 21 and 28 days. Concrete cubes containing 0% and 5% RHA cured in water were used as control.

Results and discussion

The results of the compressive strength tests to determine the optimum RHA replacement in concrete as shown in table 5 at 28 days indicate that the maximum strength increase occurs at 5% RHA content.

The results of the compressive strength of concrete cubes containing 5% RHA cured in water of different NaCl concentrations are shown in Table 6. The high values of compressive strength of concrete cubes in Table 5 compared to those of control cubes in table 6 at 28 days are due to the higher compaction achieved by manual compaction of the cubes compared to the compaction in the vibrated cubes. The results in Table 5 show that increase in RHA content in concrete causes progressive decrease in compaction factor and slump of fresh concrete; consequently concrete containing high content of RHA will be more difficult to work without the use of plasticizers. This has been attributed to the absorption of free water in the great number of mesopores existing in the RHA particles with an average pore diameter of about 80Å (Qijun et al., 1999).

Table 6 shows the effect of NaCl solutions on concrete cubes at different days of curing. The results show progressive loss of compressive strength of concrete cubes containing 0% RHA as NaCl concentration increases at 7 and 14 days; however marginal early strength increase was recorded at 3 and 21 days.

Compressive strength increase for concrete cubes containing 5% RHA cured in water starts at 21 days; the RHA does appear to cause compressive strength increase at later days as strength increase at 28 days is more pronounced. Furthermore, the results show that concrete cubes containing 5% RHA cured in NaCl solutions have compressive strength increase that increases with increase in NaCl concentration at 3 and 7 days. At 28 days, concrete cubes containing 5% RHA show compressive strength losses that tend to increase with increase in NaCl concentration. NaCl solution appears to cause early compressive strength increase in concrete that cannot be maintained long term.

At 28 days, compressive strength losses are higher for concrete cubes containing 5% RHA in NaCl solutions compared to cubes without RHA. As reported by Azad (2010), chloride ions do alter the pore size distribution of hardened cement paste and chloride solutions produce chloroaluminate and appear to cause deterioration by decalcifications that are more noticeable at later days. Chlorides are known to exist in pore solution, either chemically bound to hydration products or physically held to surface of hydration products (Yuan et al., 2010). Chlorides interact with calcium silicate hydrate (CSH) at three different levels as either chemisorbed layer on CSH, in the CSH inter layer spaces or be intimately bound in the CSH lattice (Ramachandran, 1971). Chlorides are also known to promote the leaching of $Ca(OH)_2$ and promote the formation of porous CSH involving complex reactions (Lee et al, 2000). The decalcification effects of NaCl, the formation of porous CSH and the leaching of calcium hydroxide all take their toll on concrete.

The effect of calcium hydroxide leaching becomes more pronounced in concrete containing RHA because amorphous silica present in the RHA reacts with the $Ca(OH)_2$ produced by cement hydration thus depleting the total $Ca(OH)_2$ present in the concrete.

As shown in Fig. 3, the presence of RHA in the concrete cubes investigated in this experiment does suggest that normal concrete performs better than 5% RHA concrete cubes in saline solutions.

Table 5: Effect of RHA on compressive strength of concrete cubes at 28 days (w/b=0.40).

RHA Content (%)	Slump (mm)	Compaction Factor	Average compressive strength (N/mm^2)▪
0	25	0.96	**61.9**(1.0)†
5	24	0.95	**65.6**(1.7)
10	22	0.94	**52.4**(4.4)
15	16	0.94	**35.5**(1.5)
20	12	0.92	**43.4**(1.0)
25	10	0.91	**37.7**(4.8)
30	5	0.91	**23.0**(3.3)

† standard deviation of five samples in bracket. ▪average compressive strength of five samples in bold.

Table 6: Effect of curing medium on compressive strength of concrete cubes (w/b=0.40).

NaCl concentration	RHA content	Average compressive strength (N/mm^2)▪				
		3 days	7 days	14 days	21 days	28 days
0%	0%	**22.80**(1.2)	**29.10**(0.4)	**34.60**(1.3)	**32.40**(2.4)	**40.80**(1.2)†
5%	0%	**23.80**(1.4)	**26.60**(0.5)	**30.80**(3.5)	**32.40**(1.9)	**35.00**(3.6)
10%	0%	**24.50**(0.8)	**22.80**(0.4)	**27.10**(2.0)	**32.67**(2.0)	**35.40**(2.5)
0%	5%	**21.70**(0.3)	**28.90**(0.5)	**31.80**(1.4)	**34.90**(0.9)	**45.10**(0.2)
5%	5%	**26.90**(0.4)	**31.30**(0.4)	**30.60**(0.4)	**36.20**(3.6)	**34.30**(3.8)
10%	5%	**29.40**(0.8)	**33.70**(1.1)	**32.80**(1.2)	**24.50**(1.7)	**24.60**(2.3)

†Standard deviation of five samples in bracket. ▪Average compressive strength of five samples in bold.

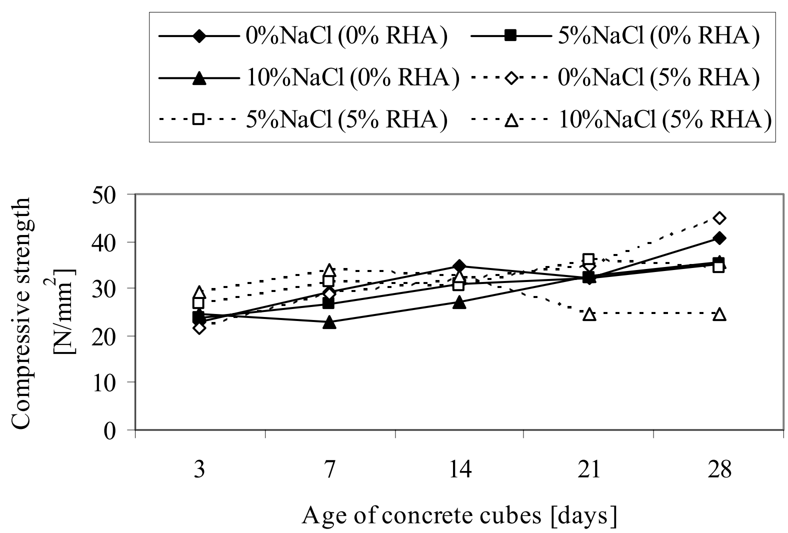

Figure 3: Effect of sodium chloride solutions of compressive strength of concrete.

Conclusion

The results of laboratory study suggest that NaCl solutions have compressive strength accelerating properties at early ages that cannot be sustained long term; the strength patterns suggest that saline solutions cause long term compressive strength loss of concrete. Though the advantages in the use of RHA in concrete have been well established in terms of improved concrete performance, the results of the investigations presented in this work indicate that normal concrete has better compressive strength performance in saline solutions than concrete containing RHA. Though the use of RHA in concrete could improve its compressive strength, the study has shown that concrete containing RHA could be more susceptible to sodium chloride attack than ordinary concrete. This is particularly relevant in coastal areas with saline environment.

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