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Electrical Resistivity of Concrete Containing Crystalline Rice Husk Ash as Supplementary Cementing Material

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Abstract

Studies have shown that supplementary cementitious materials (SCMs) improve the strength and durability of concrete, aside from these serving as cheaper partial cement replacement. This study looks into crystalline rice husk ash as an SCM and considers its effect on concrete durability by investigating the electrical resistivity of concrete specimens. Electrical resistivity indirectly measures the durability of concrete as it provides rapid indication of its resistance to corrosion. Direct current electrical resistivity tests were done on concrete samples containing 10%, 15%, and 20% rice husk ash (RHA) and results were compared with a control specimen. Electrical resistivities were determined after the concrete samples were cured for 28 and 56 days. It was found out that at 28 days curing period, electrical resistivities of concrete with 10% and 15% RHA are relatively equal with the control concrete. However, setting the curing period to 56 days resulted in higher electrical resistivity for concrete with RHA. Colorimetric test done in selected specimens validated the electrical resistivity results.

Keywords: supplementary cementitious materials, rice husk ash from open-air burning, concrete durability, resistance of concrete to corrosion

Introduction

Supplementary cementitious materials (SCMs) have been studied as suitable materials for partial replacement of cement that will yield strong and durable concrete (Lothenbach, Scrivener, & Hooton, 2011). SCMs are mineral admixtures that display cementitious property when incorporated in the concrete mix. They are generally by-products of processing natural materials like fly ash, silica fume, slag, and rice husk ash. These materials enhance the workability of fresh concrete; improve resistance of concrete to thermal cracking, alkali-aggregate expansion, and sulfate attack; and increase concrete durability against chloride induced corrosion (Whiting, Todres, & Nagi, 1993; Hisada, Nagataki, & Otsuki, 1999; Madlangbayan, Otsuki, Diola, & Baccay, 2005).

Rice husk ash (RHA) is among the most abundant SCMs, and studies have been made on its use to enhance the strength of concrete. Mahmud, Hamid, and Chia (1996) reported 15% cement replacement by RHA as an optimal level for achieving maximum strength. Zhang and Mohan (1996) noted that 10% RHA replacement exhibited higher strength than the control concrete at all ages. Ganesan, Rajagopal, and Thangavel (2008) concluded that concrete containing 15% of RHA has an utmost compressive strength, with a loss being noted at elevated content more than 15%. Dakroury and Gasser (2008) revealed that the optimum replacement level of RHA for all water-cement ratios is 30% because of its high value of compressive strength. Finally, Rodriguez (2006) concluded that RHA-blended concrete exhibited higher compressive strength at 91 days as compared to the concrete without RHA

The durability of concrete with RHA have also been investigated. In 2000, Hasparyk, Monteiro, and Carasek reported that highly reactive RHA as a partial cement replacement between 12% and 15% may be sufficient to control deleterious expansion in concrete caused by alkali-silica reaction. This may be due to the entrapment of alkalis by the supplementary hydrates and the consequent decrease in the pH of pore solutions. Sakr (2006) investigated the effect of RHA on the sulfate resistance of heavyweight concrete and found that RHA-blended concrete had good resistance to sulfate attack. The study showed reductions in compressive strength of concrete having 15% RHA replacement level when immersed for 28 days in 5% $MgSO_4$ solution. Lastly, Chindaprasirt and Rukzon (2008) and his colleagues studied the effect of RHA and fly ash on the corrosion resistance of concrete. They inferred that both fly ash and RHA are effective in improving the corrosion resistance of mortars, with RHA having better contribution to corrosion resistance.

Another measure of concrete durability is electrical resistivity, which is an important inherent property affecting the corrosion rate of reinforcing steel in concrete. Xian-yu, Zong-jin, and Nan-guo (2001) investigated the electrical resistivity of concretes with different mineral admixtures (or SCMs) such as silica fume, fly ash, and slag incorporations with similar water-binder ratios (i.e., 0.5). They found that silica fume showed rapid increase of resistivity as compared to plain concrete and to all kinds of blended concrete for curing periods greater than two days.

RHA is nearly similar to silica fume in terms of silica content; however, no study has been done on RHA's effect on the electrical resistivity of concrete. This study aims to determine the effect of crystalline RHA on the durability of concrete, focusing on the influence of crystalline RHA on the electrical resistivity of concrete when cement is partially replaced with crystalline RHA. The study will use crystalline RHA derived from uncontrolled open-air burning of rice husk, which is the common and most abundant source of RHA in the Philippines. The results will supplement existing data on the ability of crystalline RHA as cement replacement, particularly in terms of its effect on the electrical resistivity of concrete.

Methodology

Research Design

The study was designed to investigate the electrical resistivity of Type IP cement concrete that contained crystalline RHA as partial replacement of the cement. Three different percentages by mass of crystalline RHA (10%, 15% and 20% of total binding material) and a control with no RHA were considered. A total of 48 specimens were cast – 12 for each replacement level. Under each replacement level, 6 specimens were tested after 28 days curing, which is a standard curing period, and another 6 after 56 days curing to simulate long term curing. Electrical resistivity of the concrete was then determined through Electrical Resistivity Test. Test results were analyzed to determine the relationships between important variables such as electrical resistivity, RHA replacement level (%), and curing period of the specimens.

Materials and sample characterization

The RHA supplemented to the concrete mix was an end-waste product obtained from uncontrolled burning of rice husk from a local rice milling company (Irish Rice Mill, Biñan, Laguna, Philippines). The RHA was preliminarily sifted to remove unburned rice husk. Before introducing to the mix, the RHA was manually pounded with a hammer and then passed through US Standard sieve no. 50 (300μm) to ensure a relatively similar fineness with Type IP cement. Sifted RHA was stored in plastic containers to protect from moisture as shown in Figure 1.

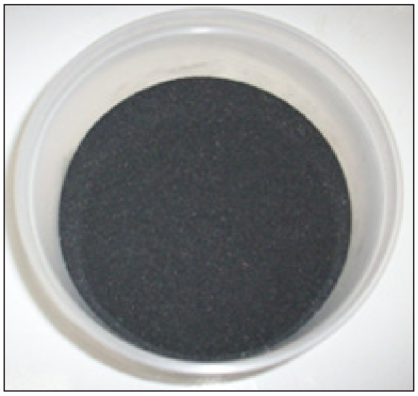

Figure 1. RHA stored in a plastic container

RHA was subjected to sieve analysis test at the Metallurgical Technology Division of the Mines and Geosciences Bureau (MGB) under the Department of Environment and Natural Resources (DENR) of the Republic of the Philippines. US Standard Sieve Nos. 60 to 400 (0.250 to 0.038mm) were used to determine the particle size distribution for the RHA as shown in Figure 2. The Fineness modulus of RHA was determined to be 3.08.

The chemical compositions of Type IP cement (Republic cement, Batangas, Philippines) and RHA were determined using X-ray fluorescence spectroscopy at MGB, DENR, Philippines. The chemical compositions are shown in Table 1. Other components that are present but are unaccounted for include Na_2O, K_2O, H_2O and Loss on ignition.

River sand was used as fine aggregates while crushed rocks, as coarse aggregates. The physical properties of fine and coarse aggregates are shown in Table 2. The particle size distribution of the fine aggregate is shown in Figure 3. The Japanese Society of Civil Engineers (JSCE, 2007) mix proportioning method was used to determine the proportions of cement, water, coarse aggregate, fine aggregates and RHA of the mixes. The details of the proportions are listed in Table 3 as the mass of each material per cubic meter of concrete.

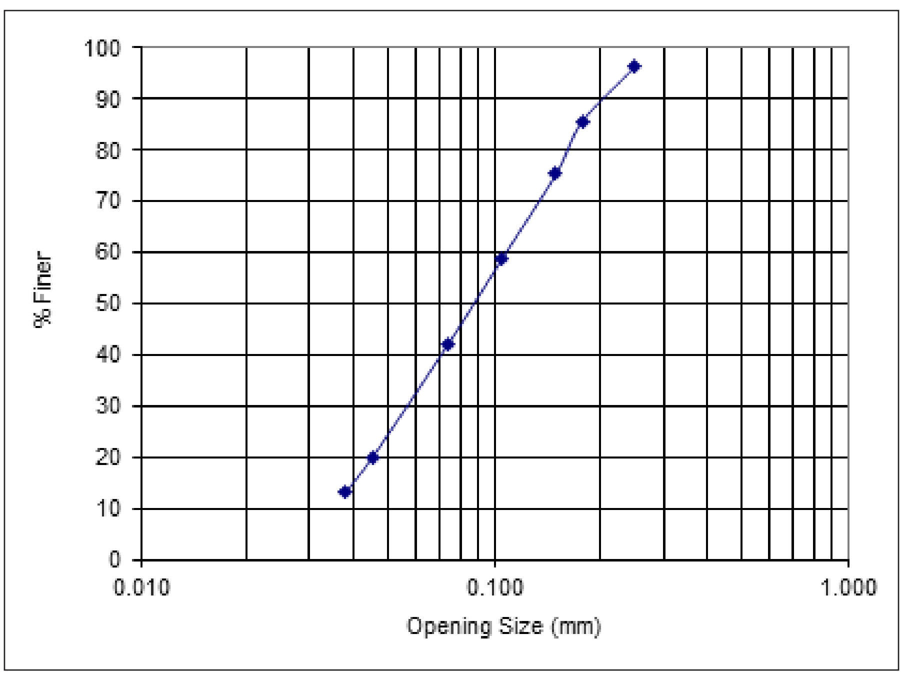

Figure 2. Particle size distribution of RHA

Table 1. Chemical composition of Type IP cement and RHA (% w/w)

Cement	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Type IP	21.45	6.00	3.50	65.00	1.18
RHA	88.91	0.078	0.021	0.44	0.37

Table 2. Physical properties of fine and coarse aggregates

Kind of aggregate	Specific gravity in Saturated Surface Dry (SSD)	Fineness Modulus
Fine Aggregate	2.36	3.88
Coarse Aggregate	2.52	7.00

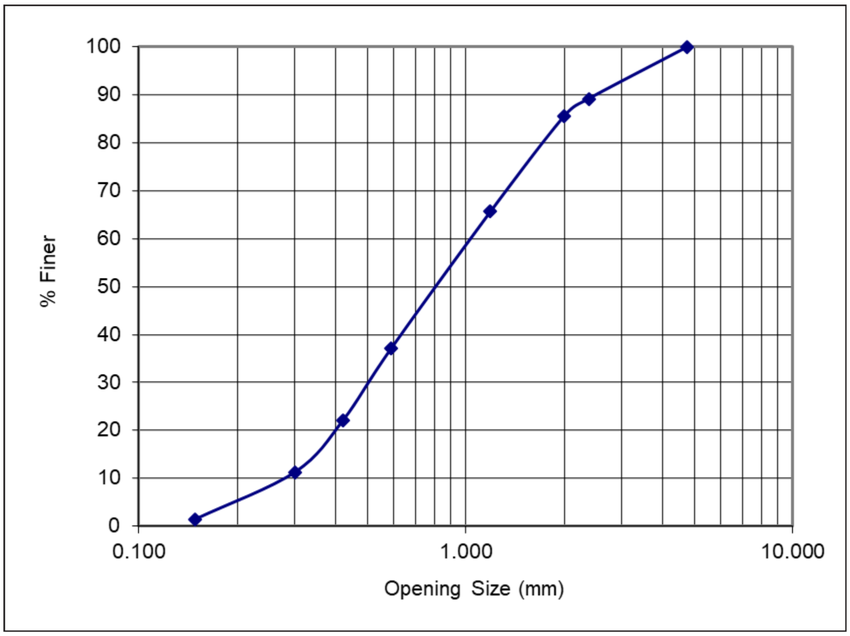

Figure 3. Particle size distribution of fine aggregates

Table 3. Mix Proportions of Concrete Constituents

% RHA	Water (kg)	Type IP Cement (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)	RHA (kg)
0	193	351	845	804	0
10	193	316	835	794	35
15	193	298	830	790	53
20	193	281	825	785	70

Preparation of test specimens

Standard cylindrical concrete parent specimens, 100 x 200 mm in size, were cast, cured and immersed in a water bath after demolding to achieve 100% relative humidity. These specimens were cured for 28 and 56 days. Test specimens for the electrical resistivity test (100 mm x 50 mm) were cut from the 100 x 200 mm parent specimens using a concrete cutter (Powercraft PCCM 400, China) with diamond tip 7-inch wheel cutting blade. Each sample had a diameter of 100 ± 6 mm and a thickness of 50 ± 3 mm. Figure 4 shows the parent specimens cast in molds side by side with the schematic diagram of the specimen cutting planes.

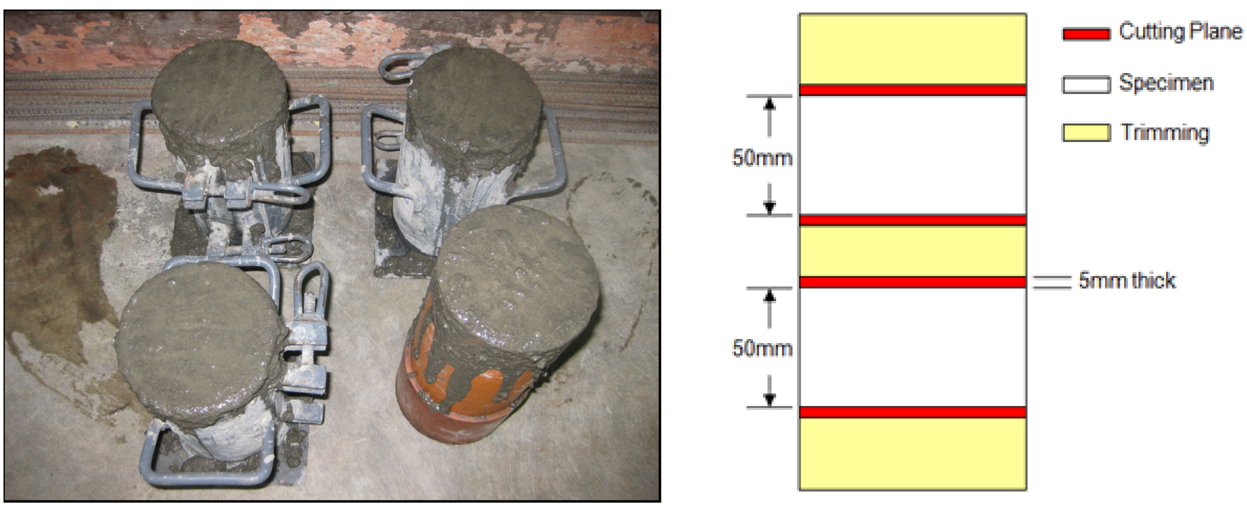

Figure 4. Parent concrete specimens cast in 100 x 200mm molds (left) with the schematic diagram of the specimen cutting planes (right)

Testing for Electrical Resistivity

Following the DC measurement technique by Monfore (1968), the test for electrical resistivity was done by applying a voltage between two stainless steel plate electrodes with the concrete specimen sandwiched in between as shown in Figure 5. Voltage was applied using a commercially available AC-DC Power Adaptor (Super APA-39100N, China) that converts alternating current (AC) voltage at frequencies between 60 Hz and 50 Hz to direct current (DC) voltage. This device could produce DC voltage outputs ranging from 1.5 to 12 V and a maximum of 350 mA of direct current. Current measurements were taken at two applied voltages to account for the effect of polarization. In the set-up, a commercially available digital multimeter (Newstar UT-20B, China) was used to measure the current and was placed in series with the voltage source and the test specimen. The steel plate electrodes were attached to the circuit using alligator clips.

The faces of the steel plates on the end surfaces of the specimen were overlaid with moist tissue paper. The moist tissue paper ensured that the electric current could pass through the gross cross-sectional surface area of the test specimen to or from the steel plate electrode. The tissue paper was not overly wet to prevent the water from dripping along the sides of the specimen, as this would make the measurement of electric current erroneous due to current travelling through the dripping film of water and not through the pores of the concrete.

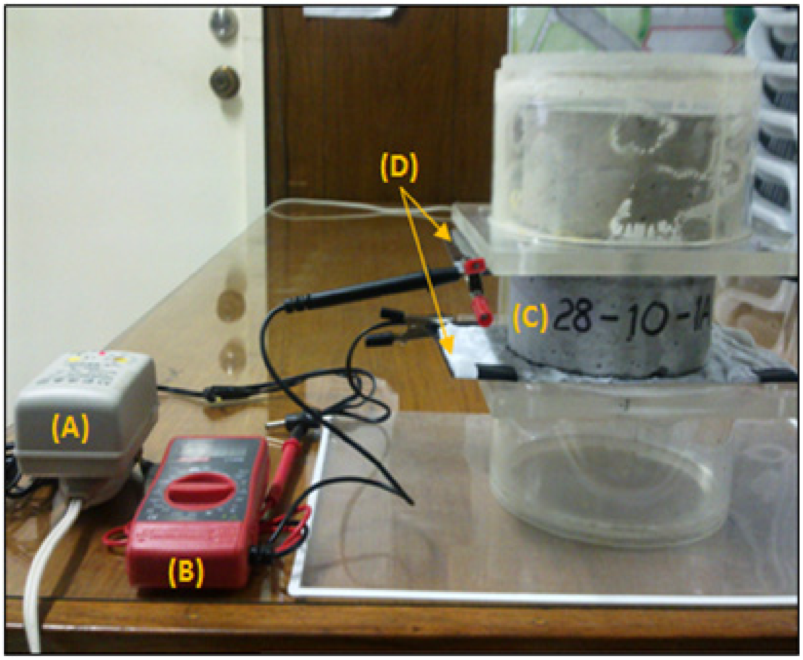

Figure 5. Test set-up for DC electrical resistivity determination, where, (A) DC Power Supply, (B) Digital Multimeter, (C) Concrete Test Specimen, and (D) Stainless Steel Plates.

The voltage supplied was closely monitored before and after current measurements to guarantee consistency of readings. With the multimeter set to DC mode, the electric current going through the specimen was determined. The steady-state value appearing on the display screen of the measuring device was recorded as the electric current corresponding to the supplied voltage.

After taking measurements, the DC resistance R (ohm) of the concrete specimen was computed using Equation (1) where E_{a1} and E_{a2} are the applied voltages (V) during the first and second current measurements respectively, while I_1 and I_2 are the currents (A) measured at voltages E_{a1} and E_{a2}, respectively. Finally, the electrical resistivity ρ (ohm-m) was computed using Equation (2) where A is the cross-sectional area (m^2) and L is the thickness (m) of the test specimen.

$$R = \frac{E_{a2} - E_{a1}}{I_2 - I_1} \quad \text{Equation (1)}$$

$$\rho = \frac{RA}{L} \quad \text{Equation (2)}$$

To provide a visual presentation of the extent to which chloride ions could penetrate through the concrete pore network, selected specimens (one from each replacement level and curing period) underwent a colorimetric test following the technique by Otsuki, Nagataki and Nakashita (1992). The specimens were immersed in a 3% NaCl solution for 30 days after undergoing electrical resistivity test. After 30 days, the specimens were fractured and the faces of the fractured part of the specimens were sprayed with a prepared 0.1 N $AgNO_3$ solution. The color change border corresponds to the location of the soluble chloride concentration that penetrated the specimen. The border depths were then measured using a digital caliper (Mitutoyo CD-8"CX, Japan). For every specimen, one fractured side was considered and 10 measurements were recorded to account for the variations in depth of the chloride penetration.

Statistical Analysis

The difference in the means of the concrete resistivities and chloride penetration depths were determined using One Way Analysis of Variance (ANOVA). Means showing significant differences (at $p<0.05$) among RHA percentage replacement levels were subjected to t-Test to determine which RHA percentage replacement level showed significantly different results from the others.

Results and Discussion

Results of laboratory measurements of concrete resistivity are shown in Table 4 and Figure 6. It should be noted that the values of electrical resistivity were computed from voltage and current measurements of test specimens whose lengths and cross-sectional areas were known. For each design mix and curing period, the electrical resistivity represented the average of resistivities of six 100 x 50 mm cylindrical test specimens.

Table 4. Mean concrete resistivities*

% RHA	Mean Concrete Resistivities (ohm-m)	
	28 days curing period	56 days curing period
0	123.61 a	217.41 a
10	128.34 a	304.23 b
15	127.34 a	314.70 b
20	74.92 b	397.72 c

*In a column, means followed by the same letter are not significantly different at $p<0.05$

Based on Table 4 and Figure 6, 28-day cured concretes did not show the same trend in electrical resistivity behavior as compared with 56-day cured concretes. At a curing period of 28 days, the highest electrical resistivity (128.34 ohm-m) was measured in 10% RHA concrete. In contrast, the lowest electrical resistivity (74.92 ohm-m) was measured in 20% RHA concrete. This value was just about 61% of the electrical resistivity (123.61 ohm-m) of the control concrete. The resistivity of 20% RHA concrete increased to

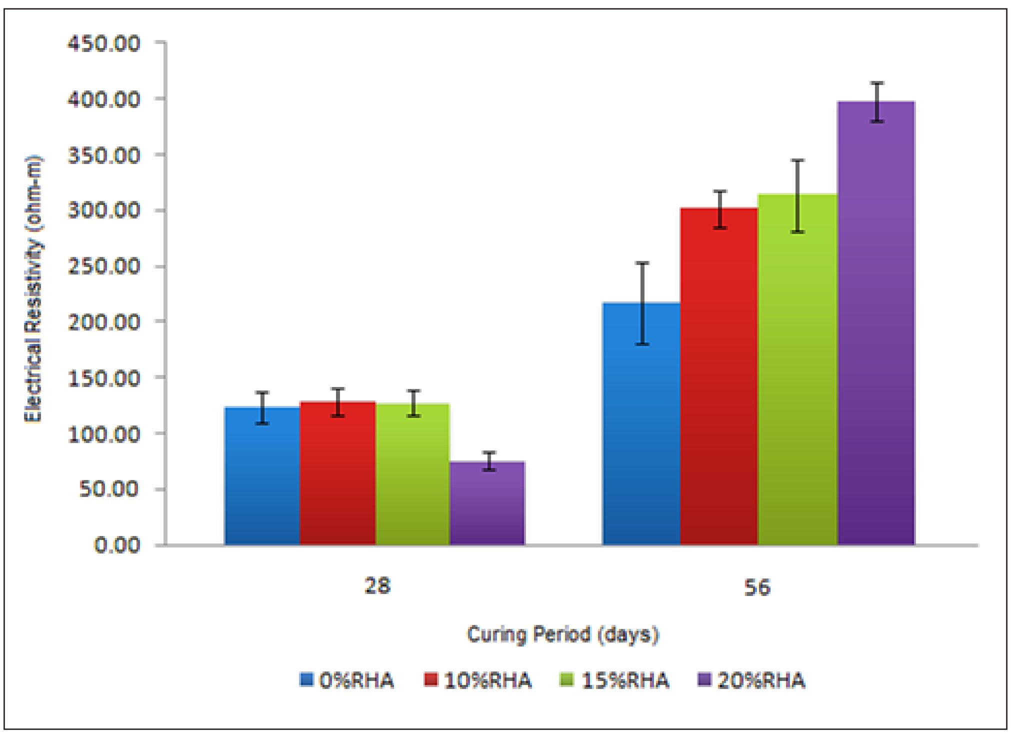

Figure 6. Electrical resistivity of RHA concrete cured for 28 and 56 days

1.83 times that of control concrete – from 217.41 ohm-m to 397.72 ohm-m.

The ANOVA results show that there is significant differences between the electrical resistivities of the RHA replacement levels with p-value < 0.001 for 28 days curing and p-value < 0.001 for 56 days curing. Post-hoc t-Tests show which average electrical resistivity is significantly different from that in another RHA replacement level as can be seen in Table 4.

With conduction taking place through the interconnected pores of the concrete, the observed behavior of concrete resistivity can be ascribed to the formation and structure of transition zones in concrete. The transition zone represents the interfacial region between the particles of the coarse aggregate and the hydrated cement paste. Because of the greater porosity and the connectivity of the pores in the transition zone, its effect on the transport properties of the concrete is significant, particularly if the individual transition zones interconnect with one another to percolate through the concrete (Mehta & Monteiro, 2006). The structure provides continuous pathways for the transport of fluid or ions, which are the carriers of electric charge during conduction, regarded as essentially electrolytic in nature. Hence, the structure of the transition zone has a great influence on the electrical resistivity of concrete.

With the incorporation of pozzolans like RHA, pozzolanic reaction takes place. This reaction consumes the highly soluble calcium hydroxide (CH) to produce more stable calcium silicate hydrates (C-S-H), which is less porous than the former. Increased formation of C-S-H leads to better structure of the transition zone. This eventually leads to higher concrete resistivity due to the decrease of voids and microcracks that allow transport of ions through the concrete.

Nevertheless, the rate of pozzolanic reaction is slow. RHA and other pozzolans are slow reacting materials, as they require a longer time to hydrate. Hence, at an early age, these materials act as filler materials to the concrete. Consequently, most of the CH's produced from the hydration of cement will become unutilized, thereby making the transition zones unstable and the pore structure undeveloped. This probably explains the relatively equal (no significant difference in the means) electrical resistivities of 28-day cured concretes at 0%, 10% and 15% RHA replacement levels, and the very low electrical resistivity measured from that of 20% RHA concrete. The amount of hydrated cement paste and hydration products of concrete with 10% and 15% RHA replacement levels might have been comparatively equal to that of the control concrete, causing their electrical resistivities to be more or less similar to the latter. However, at 20% RHA content, less amount of cementitious products brought about by the reduced amount of cement and the absence (or slow rate) of silica-calcium hydroxide (or pozzolanic) reaction might have resulted in poor concrete pore structure and, thus, low electrical resistivity.

In order to achieve the benefits of pozzolanic reaction, proper curing must be performed (Ayers & Khan, 1993; Malhotra & Mehta, 2005). In this regard, prolonging the curing to 56 days might have given sufficient time for most of the crystalline silica in RHA to react with the hydration products such as CH and thus producing a more developed pore structure. Referring back to Table 4, the electrical resistivities at 56 days, compared to electrical resistivities at 28 days, were found to be significantly different and increased by factors of 1.76, 2.35, and 2.47 for 0%, 10%, and 15% RHA contents, respectively. Most significantly, in the case of 20% RHA concretes, resistivity increased by a factor of 5.31.

Lastly, the contribution of the hydration of the cement on the improved resistivity of the concrete cannot be ruled out. Hydration of cement produces its own brand of C-S-H, helping in the development of the transition zones and decreasing the total porosity of the cement paste itself. Generally, the older the concrete, the more highly developed is its pore structure. This is because the amount of hydration increases with the age of the concrete. Accordingly, the resistivity is improved along with the enhancement of the concrete pore structure. In addition, the continuing hydration process reduces the amount of evaporable water within the cement paste, which makes conduction of electric current less efficient.

Table 5 shows the average values of the measured chloride penetration depths of specimens on the 30th day of submersion in a 3% NaCl solution. High chloride penetration depth indicates low electrical resistivity. It can be inferred then, based on Figure 6 and Table 5, that data of resistivities were consistent with chloride penetration depths. Least penetration depth for 28-day cured concretes was observed at 10% RHA replacement level. Concrete at 20% RHA replacement level and cured for 56 days exhibited about a 4-fold decrease when compared to 28-day cured concrete with statistical analysis showing a significant decrease in resistivity (at $p<0.05$). It was also found that the specimen with the most penetration of chloride ions was the one which contained 20% RHA at curing age of 28 days. In contrast, the most resistant to penetration was the 56-day cured concrete that had a replacement level of 20% RHA.

The ANOVA results indicate that there is significant differences between the chloride penetration depths of the RHA replacement levels with p-value < 0.001 for 28 days curing and p-value < 0.030 for 56 days curing. Using t-Test, the RHA level having significantly different mean of chloride penetration depth from another RHA level was determined as shown in Table 5.

Table 5. Average chloride penetration depths of specimens exposed to 3% NaCl solution

% RHA	Average Chloride Penetration Depths (mm)	
	28 days curing period	56 days curing period
0	8.17 ab	4.16 a
10	6.30 a	3.46 ab
15	7.77 b	4.05 a
20	12.06 c	2.98 b

* In a column, means followed by the same letter are not significantly different at $p<0.05$

Conclusions

Crystalline RHA helps to increase concrete electrical resistivity. High dosages of crystalline RHA (up to 20% by mass of total binder) increased the electrical resistivity of ordinary concrete. Electrical resistivity results were consistent with the measured chloride penetration depths. However, long curing period was required in order to attain the significant increase in electrical resistivity. Long-term curing provided sufficient time for the benefits of pozzolanic reaction of crystalline RHA to manifest.

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