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Re-evaluation of the AASHTO T259 90-day salt ponding test

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Abstract

There is a need to develop a better understanding of the relationship among short-, medium-, and long-term tests to assess the resistance of concrete to chloride penetration. In this contribution, a resistivity-based test is compared to a 90-day salt ponding test. The short-term (6-h) rapid chloride permeability test has been criticized for its lack of a scientific basis and poor correlation to the so-called control ponding test. Comparative testing is presented for several concrete and mortar mixtures, which suggests that if modifications are made to test procedures and methods of analysis then the relationship between the results of the resistivity-based test and the diffusion-based test is improved. The 90-day salt ponding test can be improved by using a depth of penetration approach rather than an integral chloride content and by limiting the transport process to diffusion only. Modification to the rapid chloride test by shortening the test time to 30 min did not improve the correlation to other test methods for the range of concretes studied here.

Keywords: Diffusion; Permeability; Transport properties; Silica fume; Concrete

1. Introduction

It would be advantageous if a simple, short, inexpensive test could be conducted on concrete at an early age that would predict the time to onset of corrosion of reinforcing steel in concrete exposed to chloride ion contamination. This, however, is a very tall order. The rate of penetration of the chloride ion into concrete is not easily quantified. Neither is the likelihood for corrosion to occur once the chloride gets to the reinforcing steel. Penetration rates into concrete depend on many factors, such as pore geometry, chemical reaction (long and short term), environmental conditions (fluctuations in temperature and moisture), and imperfections such as cracking.

The initiation and rate of reinforcing steel corrosion is difficult to quantify and depend on chloride concentrations as well as chemical and environmental factors. Taking these many variables into consideration it is unlikely that either a resistivity-based test procedure or a 3-month salt ponding test will completely quantify the long-term nature of chloride penetration and reinforcing steel corrosion. Nonetheless, a recent debate has arisen that pits a peculiar resistivity test against a ponding test. These tests are the ASTM C 1202 “Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration” or AASHTO T277 rapid chloride permeability test (RCPT) and the AASHTO T259 “Resistance of Concrete to Chloride Penetration” sometimes called the 90-day salt ponding test.

Whiting [1] first developed the RCPT procedure. Two electrolyte-filled chambers are attached to either side of a 51-mm thick × 95-mm diameter cylinder of concrete. A 60-V DC current is passed through the sample, and total charge is recorded after 6 h. The test was calibrated against the 90-day salt ponding test. This test involves ponding of a 3% NaCl solution on air-dried slabs for a period of 90 days. In comparing results to the RCPT, Whiting used a single parameter referred to as “integral chloride content,” which is an approximate integration of the total amount of chloride ion that has penetrated into the concrete. Whiting found that the coefficient of correlation (r^2) was 0.92, but the estimated quantitative error was 30%.

Pfeifer et al. [2] found that they obtained inconsistent test results when comparing the resistivity and ponding test procedures. Scanlon and Sherman [3] reported a substantial conflict between the two test procedures and stated that the generalized relationship found by Whiting was not valid if silica fume, fly ash, or superplasticizer was used.

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Table 1
Mixture proportions and results for Series A mortars

					RCPT total charge passed					
ID no.	w/cm	% SF	% FA	% Slag	6 h (coulomb)	30 min × 12 (coulomb)	AASHTO 90-day ponding integral chloride content %*	Depth @ 0.1% Cl^- T259 (mm)	Modified ponding diffusion coefficient D_p (m^2/s; $\times 10^{-12}$)	Depth @ 0.1% Cl^- (mm)
M1	0.30	—	—	—	3860	2459	0.37	8.8	9.59	22.0
M2	0.30	—	—	25	2012	1496	0.24	6.5	2.88	13.2
M3	0.30	—	40	—	920	811	0.23	6.7	0.81	7.7
M4	0.30	8	—	—	150	145	0.17	5.0	0.71	7.1
M5	0.30	8	—	—	205	192	0.09	3.8	0.92	8.4
M6	0.30	12	—	—	67	65	0.02	2.2	0.41	5.4
M7	0.30	8	—	25	130	120	0.12	4.1	0.52	6.6
M8	0.30	8	—	40	140	130	0.06	3.2	0.51	6.0
M9	0.30	8	40	—	120	110	0.07	3.6	0.41	5.6

* By mass of mortar.

2. Background theory

The RCPT is essentially a resistivity test [4,5]. Resistivity is the inverse of conductivity. The 90-day ponding test involves a combination of absorption, diffusion, and wicking (due to drying from the bottom side). Various methods of analysis exist for looking at the 90-day ponding test, but all are based on apparent diffusion (i.e., a factor derived from the actual penetration). The relation between ionic conductivity and apparent diffusion would be linear if several ideal conditions were true:

- The effect of pore solution concentration must be minimal, i.e., dilute solution,
- Diffusion only process must occur, i.e., no chemical reaction, sorption, changes in surface concentration, etc.
- No time-dependent changes in the pore structure.

None of these criteria can be met and a linear relationship is at best an approximation.

It is interesting to note that concentration of ions in the pore solution will affect conduction and diffusion in the opposite manner. Total conductivity will be a function of total ion concentration and should increase with concentration. Increasing pore solution concentration (of all ions) should reduce diffusion. This effect may not be important if the rate of both conduction and diffusion were controlled by the tortuosity and constrictivity of the pore structure.

3. Modifications to test procedures

It would appear that obtaining a good relationship between the two tests is difficult. This does not mean that the relationship cannot be improved on. The methods of testing and analysis conducted by Whiting [1] and others [2,3] may not have been accurate enough to produce a good relationship. The following modifications are proposed to the two basic test procedures:

- Shorten the RCPT procedure to 30 min to eliminate the effects of specimen heating
- Eliminate the partially saturated condition of the ponding samples to make diffusion the dominant process
- Control solution concentration in the salt ponding test
- Modify the method of analysis of salt ponding test data to include (1) the calculation of a diffusion coefficient from Fick's second law and (2) the depth of penetration using an accurate profile grinding method.

Table 2
Mixture proportions and results for Series A concretes

					RCPT total charge passed					
ID no.	w/cm	% SF	% FA	% Slag	6 h (coulomb)	30 min × 12 (coulomb)	AASHTO 90-day ponding integral chloride content %*	Depth @ 0.1% Cl^- T259 (mm)	Modified ponding diffusion coefficient D_p (m^2/s; $\times 10^{-12}$)	Depth @ 0.1% Cl^- (mm)
C1	0.40	—	—	—	3171	2333	0.82	13.9	19.0	30.0
C2	0.40	—	—	25	1477	1339	0.85	11.7	4.96	15.9
C3	0.40	—	25	—	2056	1745	0.79	12.3	7.65	20.7
C4	0.40	8	—	—	316	306	0.48	7.7	1.68	10.2
C5	0.31	8	—	—	121	127			2.05	9.0
C6	0.31	8	—	40	72	74			1.67	8.8
C7	0.31	8	30	—	97	100			1.88	8.7

* By mass of concrete.

Table 3
Mixture proportions and results for Series B concretes

					RCPT total charge passed					
ID no.	w/cm	% SF	% FA	% Slag	6 h (coulomb)	30 min × 12 (coulomb)	AASHTO 90-day ponding integral chloride content %*	Depth @ 0.1% Cl^- T259 (mm)	Modified ponding diffusion coefficient D_p (m^2/s; $\times 10^{-12}$)	Depth @ 0.1% Cl^- (mm)
C8	0.35	0	–	–	3168	2495	0.26	7.1	5.9	18.5
C9	0.35	7	_	_	543	637	0.13	3.9	1.9	10.2
C10	0.35	12	–	–	282	272	0.10	3.3	0.9	6.8
C11	0.40	0	–	–	3713	2742	0.43	10.5	9.4	21.3
C12	0.40	7	_	_	596	567	0.12	3.6	1.8	10.3
C13	0.45	0	–	–	5908	4968	0.62	13.2	10.5	25.0
C14	0.45	7	_	_	1783	1472	0.29	6.7	1.9	12.5
C15	0.35	0	–	–	5058	3962	0.36	9.0	8.2	24.0
C16	0.35	7	–	–	611	607	0.15	4.4	3.2	12.5
C17	0.45	0	_	_	7299	6384	0.63	14.0	12.1	30.7
C18	0.45	7	–	–	1430	1164	0.42	10.3	4.5	17.8

* By mass of concrete.

4. Mix proportions

The concrete and mortar mixtures were cast as part of two separate graduate student research programs. Group A mixtures were completed as part of research conducted by McGrath [6] and Series B as part of research conducted by Pun [7].

General descriptions of the mixture proportions are shown in the left sides of Tables 1, 2, and 3. Group A contained two series of concrete mixtures (w/cm = 0.31 and 0.40) and one series of mortar mixtures (w/cm = 0.30). Mixes contained combinations of silica fume, blast furnace slag, and Class C and F fly ash. Group B contained one series of concrete mixtures (w/cm = 0.35, 0.40, and 0.45) and silica fume contents of 0%, 7%, and 12% mass replacement of cement. Specific details of Group A are given in reference [8] and Group B in reference [9].

Series A specimens were cast into 350 × 250 × 150-mm blocks and 350 × 150 × 75-mm slabs. The specimens for chloride ponding and RCPT were cored from the interior of the larger blocks to eliminate the effects of curing and forming. Specimens for the AASHTO T259 were cured for 14 days and dried for 14 days in accordance with the standard. To allow for milling the chloride profiles, the 350 × 150 × 75-mm slabs were cored at age 14 days into 100-mm diameter cylinders and then ponded with salt solution.

Series B specimens were cast in similar molds and either steam cured using a conventional 18-h steam curing cycle or were moist cured for various combinations of times.

5. Test methods

5.1. AASHTO T259 90-day salt ponding test

Specimens were cast into 350 × 250 × 75-mm slabs. Fourteen days of moist curing was followed by 28 days of drying at 50% relative humidity and 23°C. For Series A, modifications to the standard procedure were made as follows:

1. Instead of building dams around the top of the 350 × 250 × 75-mm slabs, samples were cored (100-mm diameter) at age 14 days, 100-mm diameter cores were sealed around the outside edge using a peel-and-stick bituminous sheet to create a side seal and a dam for chloride solution, and cylinders were ponded to a depth of 1 cm with 3% NaCl solution
2. Tops were sealed completely with plastic wrap and tape to minimise evaporation
3. Samples were profile ground in 0.5- to 0.75-mm layers and not 12.5-mm layers.

For Series B the procedure outlined in the standard was followed except accurate profile grinding was completed.

The original work by Whiting [1] that developed a relationship between the RCPT and the 90-day salt ponding test used a concept referred to as "integral chloride content," which can be calculated by adding the chloride content of the uppermost eight 5.1-mm thick slices. An example of how this was approximated is shown in Fig. 1.

5.2. RCPT

The procedure followed for the RCPT was the same as that described in the ASTM C 1202 (Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration) and AASHTO T277 with the following exceptions. Specimen preparation was conducted in the same manner as for the chloride ponding specimens. Cores were 100-mm diameter (not 95 mm) and were nominally 50 mm long (not 51 mm). As per ASTM C 1202, the measured coulomb values were normalised to the standard 95-mm diameter. Vacuum saturation was for 24 h before coating with epoxy and 3 h after coating (not just 3 h after coating). The RCPTs were conducted on interior (sealed cure) specimens removed from 350 × 250 × 150-mm blocks (randomly from the middle 100 mm of core length). All tests were conducted when the specimens were 56 days old.

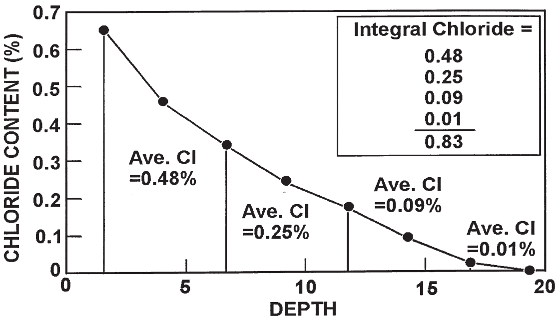

Fig. 1. Example of integral chloride content calculation.

In addition to performing the standard 6-h tests, another measure was taken to avoid the influence of temperature rise on test results. Electrical heating results in increased mobility of ions in the pore solution (i.e., increased electrical conductivity). To avoid this effect, the 30-min charge was recorded and linearly extrapolated to estimate 6-h charge passed. This is called 30 min × 12 in the tables and figures.

5.3. Modified chloride ponding test

The chloride ponding test is similar to the test described by Wood et al. [10]. The surface to be exposed to chloride solution was protected with masking tape, and the remaining sides were air dried then coated with a continuous layer of paste epoxy that was allowed to harden for up to 24 h. The tape was removed and an additional 3 h of vacuum saturation was applied in case the top surface lost moisture during the epoxying process.

Various salt concentrations, exposure times, and exposure temperatures were used throughout the two test programs; however, the results of the most highly accelerated test are provided in this paper. For this test the solution concentration was 5 mol/L NaCl and the temperature was 40°C. Samples were ponded for 120 days (first immersed at 56 days after casting). Identical 2.5-L rectangular plastic containers were used for all tests, each filled with 1.5 L of solution and two specimens. The ratio of solution volume to specimen area was kept constant to standardise the effects of leaching and counter diffusion of the OH^- ion out of the specimen. The ability of the OH^- ion to diffuse out will be influenced by its concentration in the surrounding solution as well as the diffusivity of the specimen. The concentration of hydroxide ion in the surrounding solution will be influenced by the size of the container.

5.4. Profile grinding technique

Specimens were removed from salt ponding after the required exposure period and were ground immediately. Grinding typically would be completed within 2 h of removal from solution. In a few cases where time was not available to grind immediately, specimens were tightly sealed in two plastic bags and frozen (approximately −18°C) to minimise further chloride diffusion until grinding could be completed.

At the time of grinding, a hammer and wide heavy chisel were used to chop away the outer epoxied surface and a wedge of the specimen itself along the grinding path so that this material would not contaminate the ground sample (Fig. 2). Grinding was started without delay to avoid movement of chloride ions with the evaporating pore solution.

The specimen was mounted on a Van Norman milling machine previously used for machining metal. No adjustments were needed to the machine and a simple vice and V block were used to hold the specimen. Shims were used to

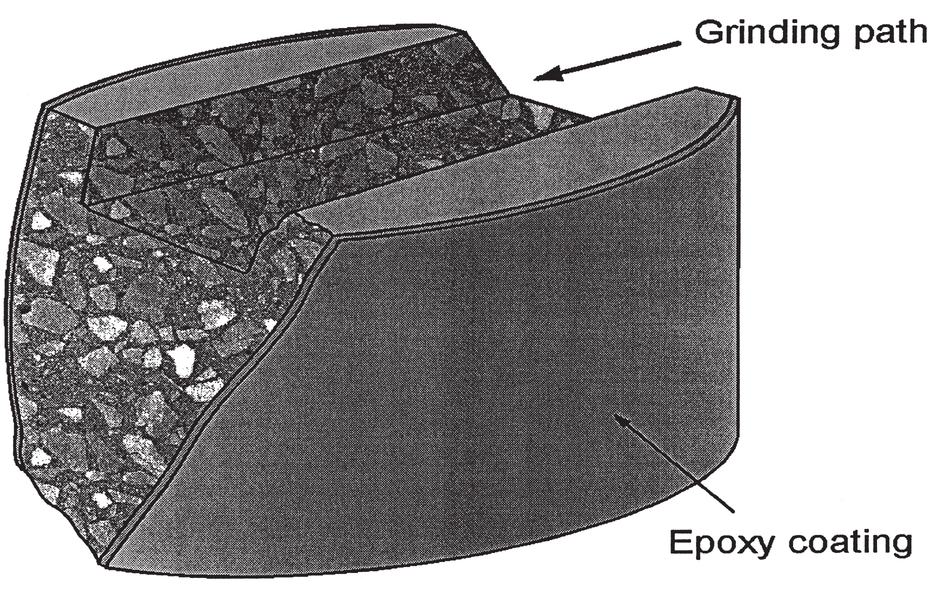

Fig. 2. Schematic diagram of profile ground specimen.

set the plane of the grinding bit parallel to the top exposed surface of the specimen. This could normally be achieved with an accuracy of ±0.20 mm. The grinding bit used was an AXT/AWT (50-mm outer diameter) ordinary diamond drill core bit such as those used in hard rock drilling. A simple adapter was made to attach the drill bit to the mill and to dissipate heat. The cross-bed travel speed (50 mm/min) and drill bit rotation (320 r.p.m.) were kept slow enough to prevent excess dusting and heat buildup. Ground layers were typically 0.51 or 0.76 mm deep (0.020 or 0.030 inch). Not every layer was saved for analysis.

Before collecting a sample for analysis, the entire area around the specimen was vacuumed and blown off with compressed air. Wax paper squares (weighing papers) were placed at either end of the direction of grinding to collect the ground powder. Approximately 90% of the ground powder could be recovered by this process; however, this amount was considered to be representative of the whole because there was little or no segregation of material from different areas of the ground specimen surface. After completion of the grinding the final ground depth was measured with a digital caliper at four locations to verify the depth readings recorded from the milling. If the final depth varied by more than 0.25 mm, all the depth readings were adjusted (making the assumption that the error occurred during the mounting and zeroing of the milling machine).

5.5. Chloride analysis

The method used for digesting the ground powders was similar to that outlined in ASTM C 114 Standard Test Methods for Chemical Analysis of Hydraulic Cement, Section 19 “Chloride.” Powder samples were first dried at 110°C to constant mass and allowed to cool in a desiccater. The material was next sieved through a 315-μm sieve. Only material passing the sieve was saved, as the larger chips retained on the sieve were likely from another layer. The reason for this is that when the milling bit first strikes the edge of the sample it chips away a bit of material below the set depth.

Immediately after sieving, either a 2 or 3-g subsample of the powder is weighed into a 250-mL beaker. The sample is digested using a nitric acid solution and brought to a boil. Some experience is necessary to determine when boiling has occurred, because effervescence (small bubbles) can be confused with boiling (large lacy bubbles). It is suggested that chloride can be lost through vaporisation if the sample is allowed to boil for any length of time [11].

After digestion and filtration the solution is analysed for total chloride content by potentiometric titration using 0.01 mol/L silver nitrate and a silver billet electrode. In some instances the chloride content of the digested solution was so low (less than 0.006 mmol) that it was necessary to add a measured volume of a known NaCl solution (unit addition or blank addition) so that a clearer inflection point would be obtained. Later the chloride content of the unit addition would be subtracted to determine the actual solution concentration.

5.6. Diffusion coefficient calculation

A typical profile from the chloride ponding test is shown in Fig. 3. The chloride content is expressed as a percentage of the 110°C dry mass of sample. Typically seven or eight layers were profile ground from each specimen. An estimation was made of the extent of penetration before grinding based on past experience. A good curve was produced when five or six points were within the chloride penetrated region and one or two points were in the uncontaminated region. For the types of concrete and mortar analysed in this work the depth of penetration varied from less than 5 mm to greater than 15 mm.

Fick’s second law of diffusion was fitted to the data using Eq. (1) to determine the apparent diffusion coefficient commonly referred to as D_a or in this work D_p:

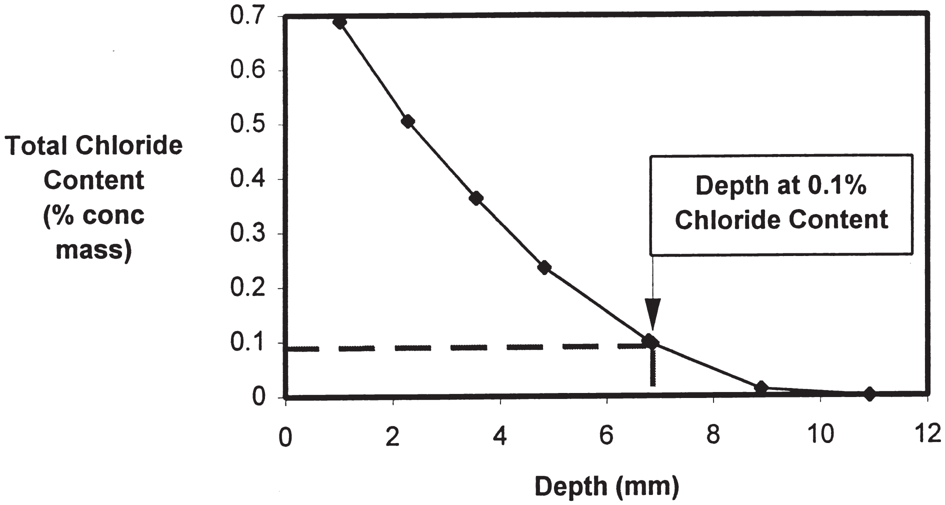

Fig. 3. Typical chloride ponding test.

Table 4
Comparison of r^2 values for linear relationship between test methods

	r^2	
Relationship	6-h RCPT	30 min × 12 RCPT
90-day ponding, integral chloride content vs. RCPT	0.34	0.30
90-day ponding, depth at 0.1% chloride vs. RCPT	0.61	0.60
Modified ponding vs. diffusion coefficient vs. RCPT	0.65	0.60
Modified ponding, depth at 0.1% chloride vs. RCPT	0.83	0.79

$$\frac{\partial c_i}{\partial t} = D\frac{\partial^2 c_i}{\partial x^2}. \quad (1)$$

For the boundary conditions $C_{(x=0,\, t>0)} = C_o$, initial condition $C_{(x>0,\, t=0)} = 0$, and infinite point condition $C_{(x=\infty,\, t(0)} = 0$, the solution is given in Eq. (2):

$$\frac{c_{(x,t)}}{c_o} = 1 - \mathrm{erf}\left(\frac{x}{\sqrt{4Dt}}\right) \quad (2)$$

where $c_{(x,t)}$ = concentration of chloride per mass of sample at distance x and time t (%); c_o = concentration of chloride per mass of sample at $x = 0$, $t > 0$ (%); and erf = error function.

This type of analysis has been used by numerous researchers to determine diffusion coefficients from either lab or field data [10–15]. The total chloride content from the titration analysis was reduced by the amount of the background chloride content, i.e., chloride present in the aggregates, cements, and other mix ingredients. The fitting of Fick's second law of diffusion was conducted using a commercial curve fitting software program to search for a nonlinear, least-squares, best fit of the data. The surface concentration C_o and diffusion coefficient (D_p) were both allowed to vary. The least-squares regression searches for the highest coefficient of determination (r^2).

5.7. Penetration depth

Fig. 3 also shows another measure of chloride penetration—the penetration depth. A value of 0.1% chloride was arbitrarily chosen as the approximate point of inflection of the "toe" of the penetration curve. This value typically will provide a precise and reproducible depth measurement. Because of the asymptotic shape of the toe of the curve, choosing a lower concentration would result in a more variable prediction of penetration depth. The 0.1% by mass of concrete value (0.3–0.6% by mass of cement depending on the mix) is likely somewhat higher than the threshold chloride level for the initiation of corrosion. A summary of various research studies compiled by Glass and Buenfeld [16] found threshold chloride levels to vary from 0.17 to 2.5% (by mass of cement) with a value of 0.2% chosen as a good prediction of threshold chloride level for harsh environments.

6. Test results and discussion

Test results are given in Tables 1, 2, and 3. To provide a degree of understanding of the dispersion of the data such that an assessment of the test procedures can be made, the

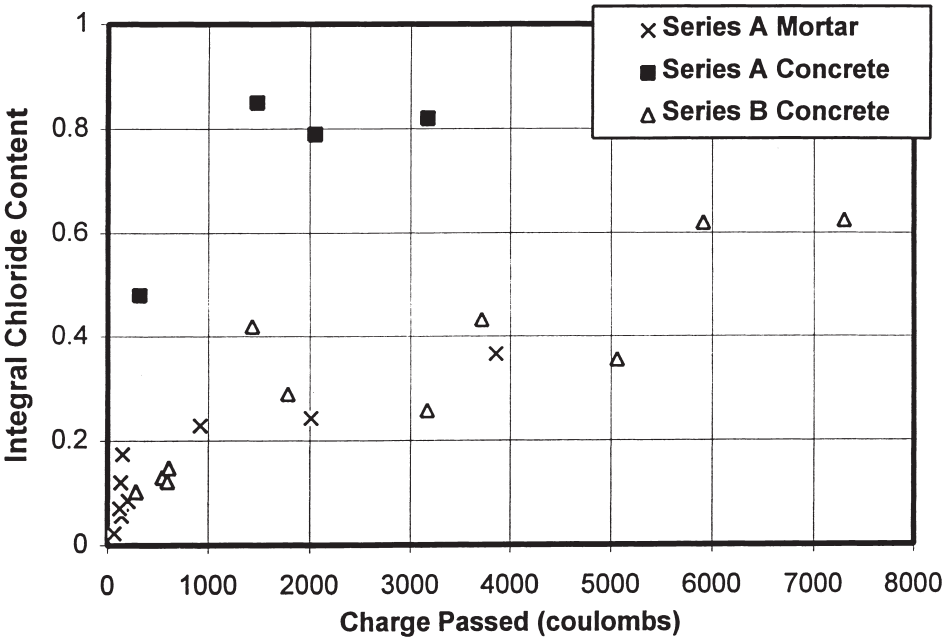

Fig. 4. AASHTO T259 integral chloride content vs. 6-h rapid chloride permeability test number.

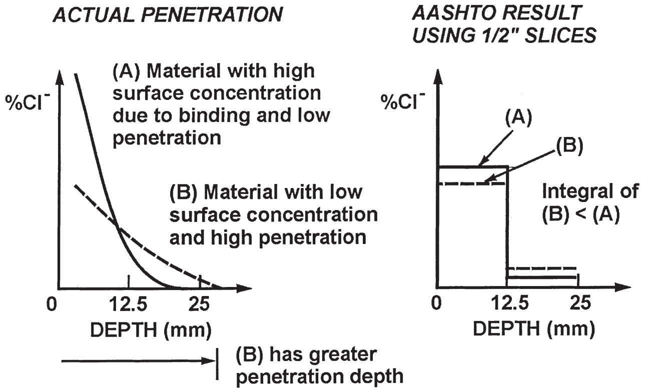

Fig. 5. Schematic diagram of the problem with integrated chloride analysis.

ponding techniques are plotted against RCPT in Figs. 4, 6, 7, and 8. The r^2 for a linear fit of the data is shown in Table 4. Also included in Table 4 is the linear fit for the modified 30-min duration RCPT.

The relationship between the integral chloride content determined from the 90-day salt ponding specimens and the RCPT number is shown in Fig. 4. As mentioned, it was a similar calculation that was used to develop the basic ranking of concrete quality for the original work by Whiting [1] on the rapid chloride test. A great deal of scatter can be seen in the data.

A problem with the integral chloride content analysis is the undue influence of high, near-surface chloride concentrations. Engineers are concerned with the advance of the critical chloride front toward the steel and not with near-surface chloride concentrations. The integral chloride content calculation penalizes concretes with high surface concentrations and low depth of penetration, relative to poorer concretes with deeper depths of penetration, yet lower surface concentration. For that reason, the depth of the 0.1% chloride advancing front analysis is preferable [6].

An example of the data obtained from the 90-day salt ponding test is shown in Fig. 4. As mentioned previously, chloride profiles were accurately measured using profile grinding. The AASHTO T259 standard calls for profiles to be obtained at two depths only, i.e., 0 to 12.5 mm and 12.5 to 25 mm. Using the more accurate profile data, the two-point data were back calculated. A comparison between the resolution of the two point method and the more accurate profile method is shown in Fig. 5. As can be seen, the two-point method unfairly represents the true depth of chloride penetration. The two-point data suggest that materials A and B are similar, when in fact the actual depth of penetration of the chlorides is nearly twice as deep in material B.

The modified (30 min × 12) rapid chloride data are plotted against the depth of penetration at 0.1% chloride for the 90-day salt ponding data in Fig. 6. A considerable reduction in the spread in the data is evident with exactly the same test specimens. The only thing that changed is the method of analysing the results. The actual penetration depth is a truer parameter of interest because it is more likely this value will influence the onset of reinforcing steel corrosion than a value weighted with surface chlorides. This was discussed by Hooton [17].

There is potentially a fundamental problem with the 90-day salt ponding test. The test appears to be intended to model field conditions and likely was developed during a

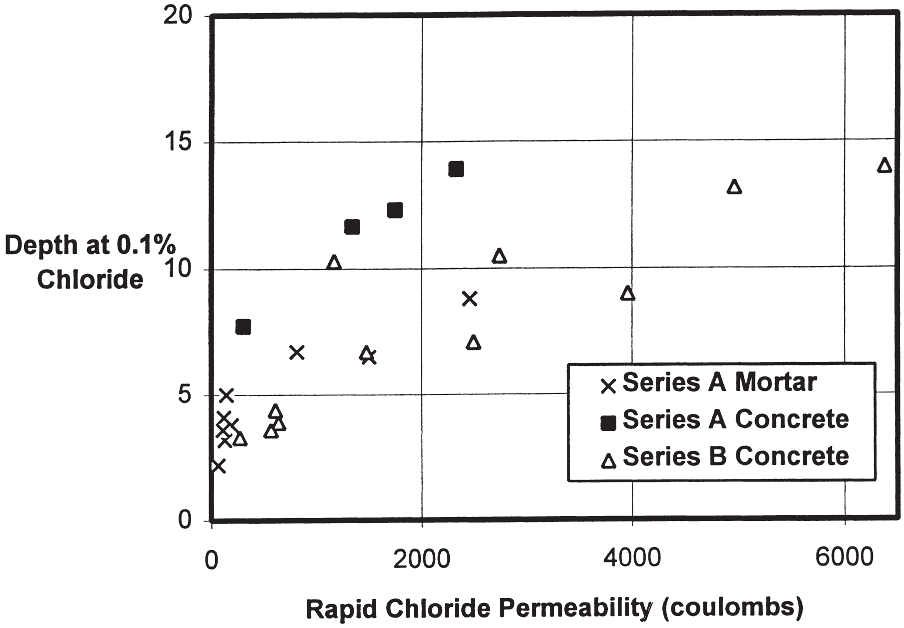

Fig. 6. AASHTO T259 depth at 0.1% vs. 30-min RCPT no. × 12.

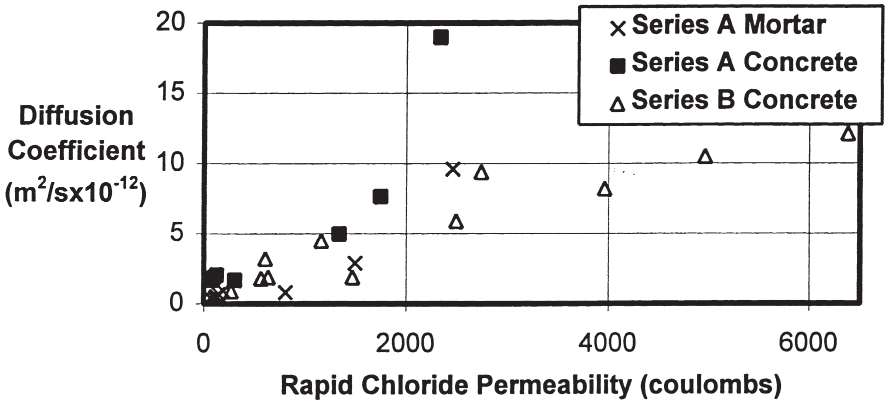

Fig. 7. Modified ponding test diffusion coefficient (D_p) vs. 30 min RCPT no. × 12.

time when ordinary Portland cement concrete of low-to-moderate w/c ratio was in common use. There are three processes at work that advance the chloride into the concrete. The samples are dried for 14 days before immersion and, therefore, suction or sorption occurs for several days, pulling chlorides well into the concrete [16]. The bottom surface of the sample is left exposed to 50% relative humidity (presumably to model the underside of a bridge deck) and wicking occurs through the sample. Diffusion occurs due to the concentration gradient of chloride. Although it can be argued that all three of these processes may be important to actual chloride penetration in the field, it is suggested here that the relative importance of the sorption component is overestimated. Furthermore, the test itself introduces errors that affect the precision of the data, such as the method of sample recovery and the variable concentration of the ponding solution. It is for this reason that the "chloride ponding/profile grinding test" on saturated samples was developed.

The diffusion coefficient determined from Fick's second law is plotted against the RCPT data for the modified ponding test in Fig. 7. A fair relationship exists; however, errors are introduced when significantly different surface concentrations of chloride influence the convergence of the equation. That the diffusion coefficient can be influenced by surface concentrations is important. Differences in surface concentration (or even the top two or three horizons) may be strongly influenced by environmental conditions and chemical binding of the chlorides, which may result in an inaccurate estimate of the true rate of diffusion.

The best correlation (assuming a linear relationship between a "medium-term" ponding test and the "short-term" AASHTO T277 RCPT) is shown in Fig. 8. In this final case the penetration depth at 0.1% for the chloride ponding/profile grinding test is plotted against the modified rapid chloride data. Fig. 8 suggests that critics of the RCPT may need to look to their own standard correlation test procedure for

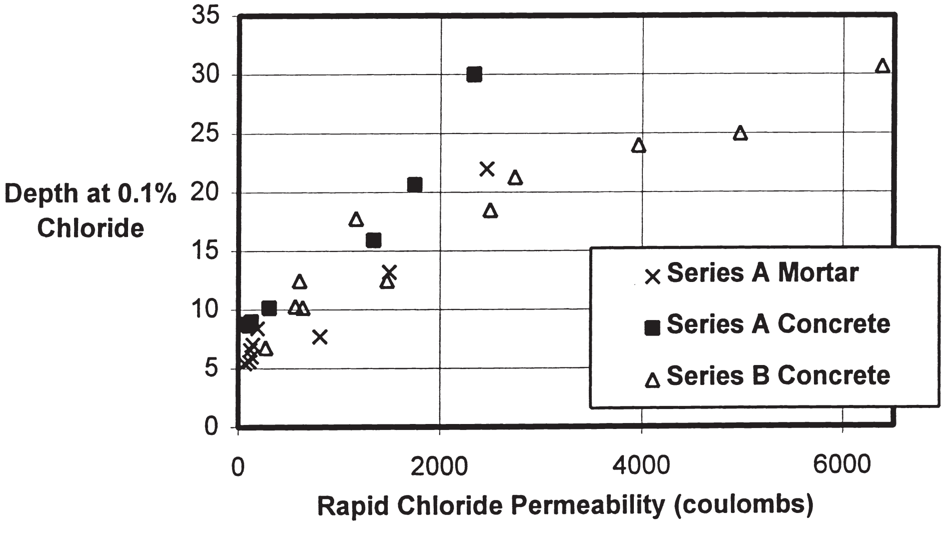

Fig. 8. Modified ponding test depth at 0.1% vs. 30-min RCPT no. × 12.

answers as to why a poor correlation with RCPT was found. The good correlation between the RCPT and the chloride ponding test suggests that a conduction-type test might be a useful indicator of long-term chloride penetration.

It is generally agreed that the numerical value obtained in the RCPT is a measure of conductivity and that there is no need to extend the test time beyond the period necessary to overcome initial polarisation (likely a few minutes). By using the 30-min value of charge passed and multiplying by 12, a RCPT value is obtained before significant heating can occur. This effect is shown in Fig. 9. It can be seen that at very low RCPT values, the two methods give the same value within 10%. However, as the RCPT values increase, the difference increased dramatically. For the normal Portland cement mortar (M1), the standard method is 44% higher than the extrapolation method. The heating effect tends to exaggerate the poor quality of poor-quality material. It is interesting that the mortar samples have a slightly different relationship than the concrete possibly due to different thermal properties of the two materials groups. This may suggest that variations in test procedure or mix ingredients may significantly influence heating characteristics.

When the same 6-h RCPT data are substituted with the 30 min × 12 data in the four relationships shown in Figs. 4, 6, 7, and 8, there is very little change in the fit of a linear relation to the data. The r^2 value is slightly reduced, as shown in Table 4. It would appear that for the types of mixes tested in this research, the effect of specimen heating during the RCPT test is no problem. This needs to be investigated in greater detail for a wider range of materials.

7. Conclusions

1. The RCPT (AASHTO T277) and the 90-day salt ponding test (AASHTO T259) were found to be poorly correlated when the standard tests were conducted and the T259 data was analysed in the conventional manner (i.e., integral chloride content).
2. The use of 12.7-mm layers for chloride content in the 90-day salt ponding test together with the integral chloride content approach can give a significantly false indication of the depth of chloride penetration, particularly in the case of high-quality concrete where the overall depth of penetration is small.
3. No improvement in the relationship between the RCPT (AASHTO T277) and ponding tests was obtained when the RCPT was shortened to 30 min for the range of mixes tested.
4. The use of a well-controlled "diffusion only" ponding test improves the precision of the chloride penetration profile and may more accurately reflect the extent of long-term penetration of chloride into concrete than a test such as the AASHTO T259 90-day salt ponding test (which includes the effects of sorption and wicking).
5. The depth of penetration of the toe of the advancing diffusion front can be conveniently taken at 0.1% chloride content (by mass of sample). However, this depth of penetration can be precisely reproduced in the chloride ponding test described herein. This is not a chloride threshold for corrosion.
6. The good experimental correlation between the RCPT

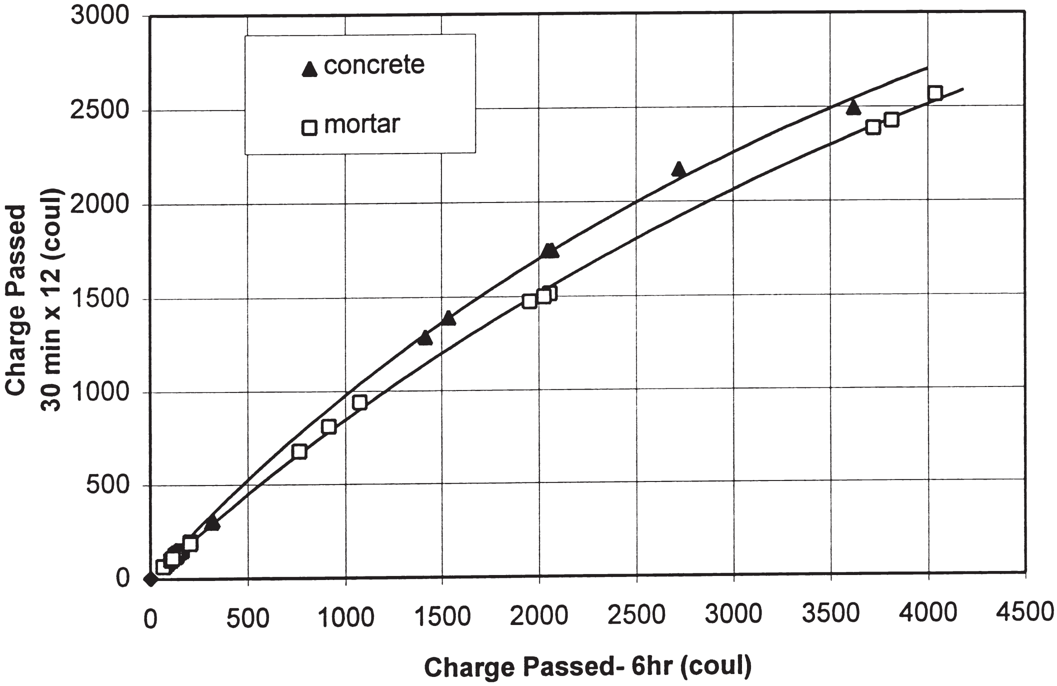

Fig. 9. RCPT plot of 6 hr charge passed versus 30 min charge ×12 [6].

and the chloride ponding test suggests that a conduction-type test might be a useful indicator of long-term chloride penetration, even though processes such as binding are not considered in the rapid tests.

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