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Investigation of the Rapid Chloride Permeability Test



by Rolf F. Feldman, Gordon W. Chan, Réjean J. Brousseau, and Peter J. Tumidajski

High-quality impermeable concrete as cover of reinforcing steel is one of the best methods of preventing chlorides from initiating corrosion. AASHTO T 277 and the ASTM C 1202-91 Rapid Chloride Permeability Test were developed because of a need to rapidly measure permeability of concrete to chloride ions. Some criticisms have been made, mainly concerning the fact that conditions under which measurements are made may cause changes to the specimens. This work was designed to observe how changes in the testing procedure affect results. Factors such as temperature, AC impedance, initial DC current, charge passed, and chloride ion profiles were monitored during polarization of four different concretes. It was found that simple measurement of initial current or resistivity gave the same ranking as conventional tests for the four concretes and can replace the rapid chloride test with a considerable time saving.

Keywords: chlorides; concretes; conductivity; corrosion; durability.

Steel reinforcement corrosion is well recognized as one of the main causes of the premature deterioration of such concrete structures as bridges and parking garages.^{1,2} Reinforcement corrosion is induced primarily by ingress of chlorides into uncontaminated concrete,³ e.g., from deicing salts, that penetrate through the concrete cover to break down the passive oxide film that normally protects the steel.

Preventing the ingress of chlorides to the reinforcement is one approach to improve the durability of a concrete structure. This can be done with thicker concrete cover and, more importantly, with concrete highly impermeable to chloride ions. This explains the need for tests that can be used in the field to rapidly measure the permeability of concretes to chloride ions.⁴

Much work has been done in measuring concrete permeability through the steady-state flow of water under a hydraulic gradient,⁵ but this test was considered somewhat irrelevant to bridge decks and it presents considerable difficulty with regard to its application and reproducibility.⁶

The main mechanism for transport of chloride ions through crack-free concrete is diffusion. This has been demonstrated by several researchers⁷⁻¹¹ using the classical diffusion cell. However, this method requires considerable time for completion, since steady-state values are required. Therefore, it is not suitable for the purpose of a rapid test.

The need for a rapid test has led to a technique that uses a

voltage gradient to force the chloride ions to migrate more rapidly through the porous materials under test. However, this approach is frequently regarded as an indirect way of measuring chloride ion permeability.⁴ This early work led to AASHTO T 277 and the ASTM C 1202-91 Rapid Chloride Permeability Test. Researchers¹² have carried out experiments that examined the effect of a) various forms of pre-soaking and prevacuum treatment of the specimens; b) different screen materials; and c) specimen diameter. Other work was directed at a study of factors relating to the reproducibility of the results.¹³ The rapid chloride test has been used in studies on the effect of pozzolanas and supplementary materials on concrete resistance to chloride ion penetration,^{14,15} and has been specified increasingly for use in parking garage slab placements and on shotcrete repair jobs.¹⁶

Recently some doubts have been expressed regarding the rapid chloride test. The main criticism is that the measurement conditions are severe and may cause both physical and chemical change in the specimen, resulting in unrealistic values.

The present work was designed to observe how changes in experimental conditions and the specimens affected results. Temperature, AC impedance, DC current, charge passed, and chloride ion profiles were monitored during the application of voltage.

RESEARCH SIGNIFICANCE

The rapid chloride penetration test involves determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. This test is now ASTM C 1202-91 and is applicable to types of concrete where correlations have been established between its procedure and long-term ponding procedures, such as those described by AASHTO T 259.

The test is now widely used to assess relative quality of

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Gordon W. Chan is a Technical Officer in the Materials Laboratory at the Institute for Research in Construction, National Research Council of Canada. He has worked in the Materials Laboratory for 12 years. Much of his work has been devoted to the study of microstructure of cement past and concrete, and, recently, rapid chloride ion permeability and diffusivity.

Réjean J. Brousseau obtained his doctorate in electrochemistry from the University of Ottawa in 1989. Since then, he has been working in the Materials Laboratory of the Institute for Research in Construction, predominantly in the area of durability of reinforced concrete. He is an active member of the National Association of Corrosion Engineers.

Peter J. Tumidajski obtained his PhD from the University of Toronto in 1987. Subsequently, he spent 18 months at the Argonne National Laboratory, and 3 years as Assistant Professor of Materials Engineering at the University of Western Ontario in London, Ontario, Canada. He is currently engaged as a Research Assistant in the Materials Laboratory of the Institute for Research in Construction at the National Research Council of Canada. His interests relate to the durability and physicochemical measurements of cement and concrete properties.

concrete in the transportation sector and is also often specified for use in parking garage slab placements and in the performance of shotcrete repair jobs. However, the test takes a relatively long time and the conditioning imposed on the samples (60 volts) is severe, causing, in many cases, heating and physical and chemical changes to the specimen.

This paper studies effects that occur in specimens during the test, and during several modified procedures. Correlations are made between the test and greatly simplified procedures, which reduce the period of severe conditions and considerably shorten the length of time taken to perform the test.

EXPERIMENTAL

Material and specimen preparation

Concrete cylinders approximately 200 mm (7.87 in.) long and 102 mm (4.02 in.) in diameter were cast. The middle 51 mm (2.01 in.) of each cylinder was used as a specimen. ASTM Type I cement was used (Table 1). The concrete was mixed at a water-cement ratio of 0.55 with a cement-sand-coarse aggregate ratio of 1:2:3. Maximum aggregate size was 19 mm (0.75 in.). The coarse aggregate used was crushed limestone. Five different maturity levels of concrete were studied: 1, 4, 6, 28, and 68 weeks.

Experiment sequence

The rapid chloride permeability technique was conducted using different solutions in the electrode reservoirs. These are summarized in Table 2 and referred to as Methods 1 through 4. Method 3 follows the conventional AASHTO T 277 procedure, while in Method 4 only, a saturated calcium hydroxide solution is used to fill both reservoirs. In all four methods, the voltage was applied for 6 hr, removed, and the specimens were allowed to cool to room temperature. The voltage was again applied for 6 hr. Three periods of 6 hr each were generally used on each specimen. In the case of the 1-week-old specimen, the sample rapidly became very hot on polarization and the application time had to be reduced to a

Table 1—Chemical composition of Type 10 cement

Element	Percent
SiO ₂	21.39
Al ₂ O ₃	5.26
Fe ₂ O ₃	2.07
CaO	66.35
MgO	1.55
Na ₂ O	0.09
K ₂ O	1.00
C	—
LOI	0.35
SO ₃	1.42
Free lime	0.94
C ₃ S	65.06
C ₂ S	12.25
C ₃ A	10.44
C ₄ AF	6.30

Table 2—Details of Methods 1 through 4 for applying voltage to concrete specimens

Methods	Voltage, DC	Time, hr	(+)	(-)
1	60	6	NaOH	NaOH
		6	NaOH	NaOH
		6	NaOH	NaOH
2	60	6	NaCl	NaOH
		6	NaCl	NaOH
		6	NaCl	NaOH
3	60	6	NaOH	NaCl
		6	NaOH	NaCl
		6	NaOH	NaCl
4	60	6	Ca(OH) ₂	Ca(OH) ₂
		6	Ca(OH) ₂	Ca(OH) ₂
		6	Ca(OH) ₂	Ca(OH) ₂

3-hr period. AC impedance measurements were recorded before and after each polarization period after the samples cooled to room temperature. In addition, the DC current passing and temperature were measured during the experiments. The total charge passed in each test was determined by integration of the current-time curves.

In another experiment, four specimens (concrete cured for 28 days) were subjected to polarization for 6, 12, 18, and 24 hr, respectively, using Method 3. The voltage was removed after each 3-hr period during the first 12 hr. Current and resistivity were measured at room temperature before and after the voltage was applied; current was also measured throughout the period. The last two specimens were subjected to one and two additional 6-hr periods, respectively. Chloride profiles were measured on each of the four specimens; average values of three specimens were taken at depths of 0 to 2 mm (0 to 0.079 in.), 8 to 10 mm (0.32 to 0.39 in.), 24 to 26 mm (0.95 to 1.02 in.), and 48 to 50 mm (1.89 to 1.97 in.) from the surface near the cathode.

Impedance measurements

Resistivity values were calculated from impedance measurements. These measurements were performed with an LCR meter at a frequency of 10 KHz. In this frequency range, no significant contribution from the measuring electrodes to the total impedance¹⁷ was recorded. The impedance

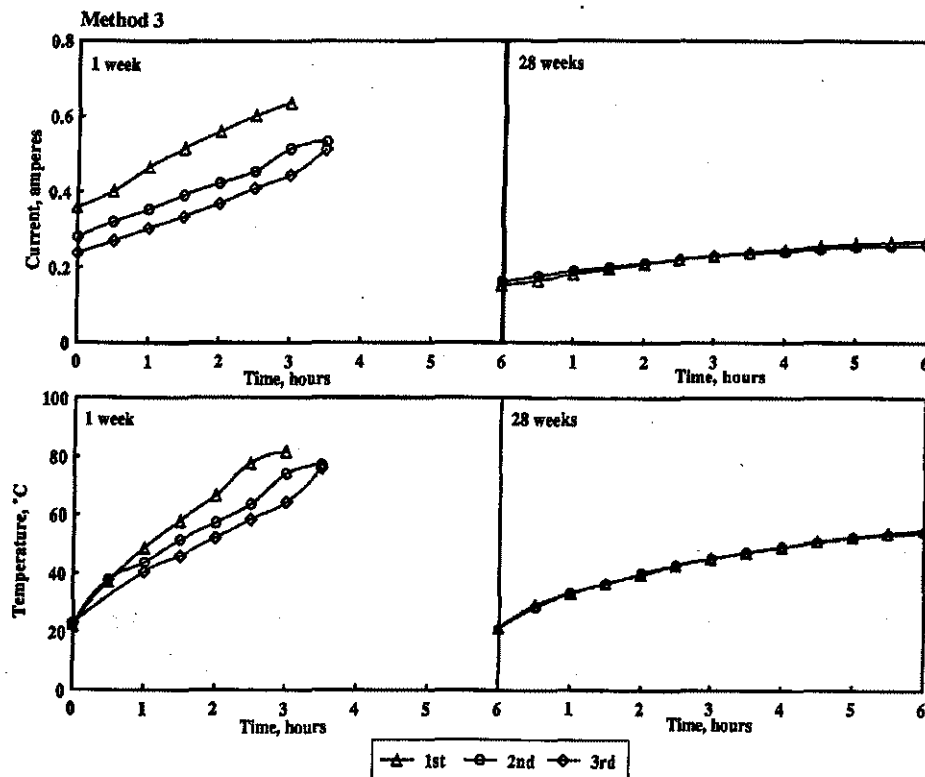


Fig. 1—Current and concomitant temperature versus time during polarization by Method 3

of the samples was measured in two ways. In the first method, impedance was measured before the specimens were installed in the permeability equipment. The slices of concrete were sandwiched between two damp cloths and two stainless steel plates (Type 304). Special care was taken to insure that the stainless steel plates were parallel during measurements. In the second method, impedance was measured through the electrodes while the concrete specimens were in the electrode solution. A small correction was made for the impedance of the electrolyte. The resistivities differed on average by 1 percent.

RESULTS

Measurements made during performance of rapid chloride permeability technique

Current and temperature measurement during polarization—Current and temperature measurements taken from the beginning of the polarization period (using Method 3) are presented in Fig. 1 for concretes cured for 1 and 28 weeks. The three cycles were carried out for only 3, 3.5, and 3.5 hr on the 1-week-old specimens; currents and temperatures increased steadily with time for all three cycles. The current at the beginning of each cycle was considerably lower than for the previous cycle. It was measured at room temperature, and the temperature increased to over 80 C for the first cycle, and almost that for the other two cycles (Fig. 1). Final currents were measured at elevated temperatures and were up to 75 percent greater than the initial current; the younger the concrete, the greater the difference. Results for the concrete cured for 28 weeks showed little difference between cycles for the initial or final current, although temperatures in-

creased to about 55 C. In general, the results showed that differences between initial and final currents and temperatures are greater with lower maturity concretes and decrease with maturity. The total charge passed, along with the initial and final currents, all decreased from Cycle 1 to 3. Measurements of initial and final current and temperature, and charge passed, on the four concretes using the four methods, are presented for the first cycle only in Table 3. Results are similar for Methods 1, 2, and 3, but for Method 4, on 28-week-old concrete, charge passed, final current, and final temperature are considerably lower than for the other methods, despite the fact that the initial currents are similar.

Measurements of current and resistivity (after cooling) during polarization cycles—Results of the measurement of current and resistivity, before and after each cycle, after the specimens had attained room temperature, are presented in Tables 4 and 5, respectively (for the four concretes and four methods). Results for charge passed in each cycle are presented in Table 6. Plots for the change of resistivity of the concretes with time of polarization by the four methods are presented in Fig. 2. A decrease in current with total time of polarization occurs by Method 1 for both the 1- and 6-week-old week concretes (Table 4); this is accompanied by an increase in resistance for both concretes (Fig. 2), although it is much greater for the 1-week-old concrete. The increase in resistance is probably due to the continued hydration with accompanied decrease in porosity and pore sizes. These processes are accelerated by the elevated temperatures brought on by the passage of the current, but at the same time the conductivity of the pore solution is increased by the temperature increases, resulting in current increases. The charge

Table 3—Measurement of initial and final current and temperature on polarization for first cycle by Methods 1 through 4

Method 1—First 6 hr				
Time, weeks	Charge passe coulombs/6 hrs	Initial current, amp	Final current, amp	Final temperature, C
1	13100	0.423	0.763	85.7
6	7475	0.222	0.387	68.9
28	5130	0.159	0.279	56.0
68	2504	0.102	0.127	38.1
Method 2—First 6 hr				
28	5726	0.169	0.325	59.1
68	2887	0.109	0.150	42.1
Method 3—First 6 hr				
1	10944	0.359	0.635	81.7
6	6729	0.227	0.450	66.1
28	4892	0.153	0.272	54.9
68	1773	0.078	0.084	34.5
Method 4—First 6 hr				
28	3781	0.143	0.166	44.0
68	2118	0.099	0.099	29.4

Table 4—Comparison of initial current for different concretes during application of Methods 1 through 4

	Hydration time, weeks									
	1			6			28		68	
	Total time, hours	Current, amps	Change, percent	Total time, hours	Current, amps	Change, percent	Current, amps	Change, percent	Current, amps	Change, percent
Method 1	0	0.423	0.00	0	0.227	0.00	0.159	0.00	0.102	0.00
	3	0.335	-20.80	6	0.225	-0.88	0.172	8.18	0.103	0.98
	6.5	0.290	-31.44	12	0.198	-12.78	—	—	0.101	-0.98
Method 2	—	—	—	0	—	—	0.169	0.00	0.109	0.00
	—	—	—	6	—	—	0.199	17.75	0.107	-1.83
	—	—	—	12	—	—	—	—	0.104	-4.59
Method 3	0	0.359	0.00	0	0.222	0.00	0.153	0.00	0.078	0.00
	3	0.279	-22.28	6	0.190	-14.41	0.163	6.54	0.076	-2.56
	6.5	0.238	-33.70	12	0.166	-25.23	—	—	0.073	-6.41
Method 4	—	—	—	0	—	—	0.143	0.00	0.099	0.00
	—	—	—	6	—	—	0.160	11.89	0.086	-13.13
	—	—	—	12	—	—	—	—	0.083	-16.16

Table 5—Comparison of resistivity for different concretes during application of Methods 1 through 4

	Hydration time, weeks									
	1			6			28		68	
	Total time, hours	Resistivity, ohm-cm	Change, percent	Total time, hours	Resistivity, ohm-cm	Change, percent	Resistivity, ohm-cm	Change, percent	Resistivity, ohm-cm	Change, percent
Method 1	0	1615	0.00	0	3033	0.00	4328	0.00	6252	0.00
	3	2029	25.63	6	3043	0.33	4023	-7.05	6246	-0.10
	6.5	2316	43.41	12	3406	12.30	3594	-16.96	6179	-1.17
	10	2439	51.02	18	3520	16.06	—	—	6259	0.11
Method 2	—	—	—	0	—	—	4255	0.00	6289	0.00
	—	—	—	6	—	—	3778	-11.21	6136	-2.43
	—	—	—	12	—	—	3106	-27.00	6112	-2.81
	—	—	—	18	—	—	—	—	6299	0.16
Method 3	0	1866	0.00	0	3147	0.00	4328	0.00	8708	0.00
	3	2363	26.63	6	3407	8.26	4022	-7.07	8275	-4.97
	6.5	2725	46.03	12	3894	23.74	3595	-16.94	8489	-2.51
	10	2818	51.02	18	4003	27.20	—	—	8501	-2.38
Method 4	—	—	—	0	—	—	4633	0.00	6790	0.00
	—	—	—	6	—	—	4206	-9.22	7328	7.92
	—	—	—	12	—	—	4145	-10.53	7939	16.92
	—	—	—	18	—	—	—	—	8232	21.24

Table 6—Comparison of charge passed for different concretes during application of Methods 1 through 4

	Hydration time, weeks									
	1			6			28		68	
	Total time, hr	Charge passed, Coulombs/6 hr	Change, percent	Total time, hr	Charge passed, Coulombs/6 hr	Change, percent	Charge passed, Coulombs/6 hr	Change, percent	Charge passed, Coulombs/6 hr	Change, percent
Method 1	3	13100	0.00	6	7475	0.00	5130	0.00	2504	0.00
	6.5	11302	-13.73	12	7721	3.29	5813	13.31	2421	-3.31
	10	9804	-25.16	18	6096	-18.45	—	—	2401	-4.11
Method 2	—	—	—	6	—	—	5726	0.00	2887	0.00
	—	—	—	12	—	—	7327	27.96	2686	-6.96
	—	—	—	18	—	—	—	—	2631	-8.87
Method 3	3	10944	0.00	6	6729	0.00	4892	0.00	1773	0.00
	6.5	8408	-23.17	12	5801	-13.79	4865	-0.55	1563	-11.84
	10	7288	-33.41	18	4778	-28.99	—	—	1576	-11.11
Method 4	—	—	—	6	—	—	3781	0.00	2118	0.00
	—	—	—	12	—	—	3537	-6.45	1840	-13.13
	—	—	—	18	—	—	—	—	1708	-19.36

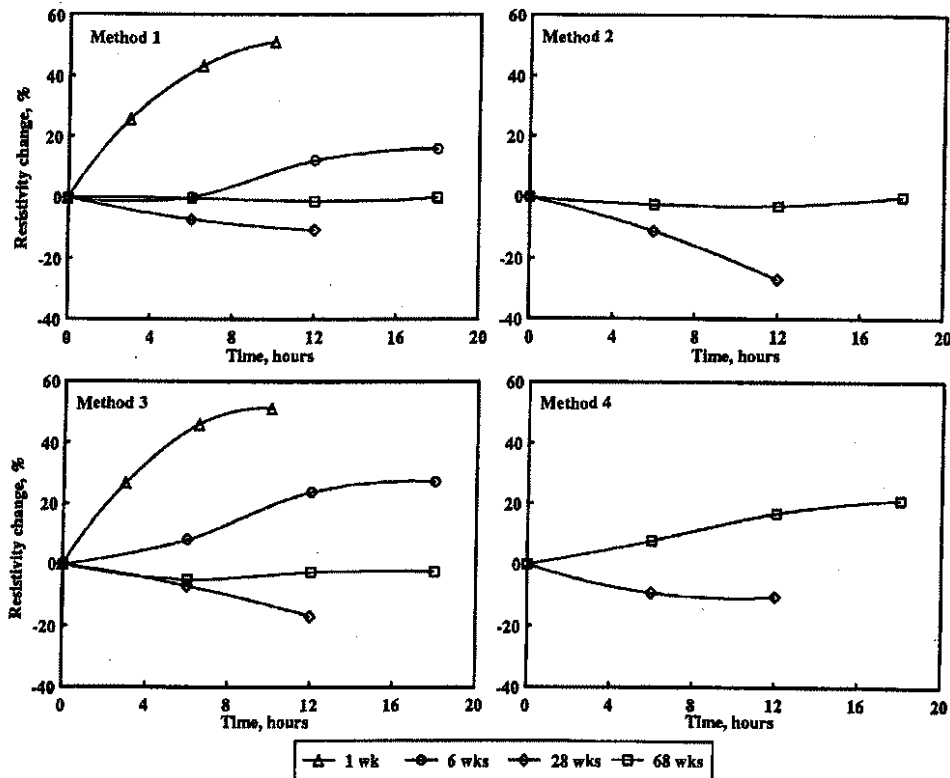


Fig. 2—Resistivity change at room temperature versus time of polarization of four concretes by Methods 1 through 4

passed per unit time is much greater for the 1-week-old concrete than the 6-week-old concrete. The 28-week-old concrete, however, shows an increase in current and decrease in resistance, while the 68-week-old concrete shows little change in either. For the 28-week-old concrete, this is probably due to sodium and hydroxyl ions entering the concrete, increasing the conductivity of the pore solution, while the change in pore structure due to further hydration is slight. For the 68-week-old concrete, changes in the pore structure and solution concentrations are probably slight. These results reflect those for the charge passed through the specimens.

The results for Method 2 involve only the 28- and 68-week-old concretes. They differ from Method 1 only in that the decrease in resistance and increase in current for the 28-day-old concrete is significantly greater for Method 2. These trends continue with the value of the charge passed through the specimen, which is much greater for Method 2 and the 28-day-old concrete specimen.

Results for Method 3 show a more rapid decrease in current and increase in resistance with time of polarization than for Method 1 for the 1- and 6-week-old concretes. Consequently, the charge passed through the specimens is also less over the equivalent time period. This may be due to the ac-

celerating influence of the chloride ion on hydration rate, since this ion migrates to the anode in Method 3. In addition, hydroxyl ion migration adding to the conductivity of the pore solution in Methods 1 and 2 will not occur in this case. In Method 3, for the 28-week-old concrete, a significant increase in current, and a significant decrease in resistivity, are observed, but to a lesser extent than for Method 2. This reflects both the increased conductivities of the pore solutions due to the respective migration of chloride and hydroxyl ions, but also the fact that hydroxyl ion is more conductive than chloride ion, and, finally, that part of the latter is immobilized from solution by reacting with the aluminates phases in the hydrated cement. Results for the 68-week-old concrete are similar to Methods 1 and 2 in that no significant changes in current, resistance, and charge passed are observed.

Results from Method 4 also display increases of current and decreases of resistance with time for the 28-week-old concrete when the system is polarized. The charge passed, however, decreases. The decrease in resistance is greater than for Method 3, for the first 6 hr, but for the second period, it is much less, and the charge passed is also much less than in Method 3. It is interesting to recall that the initial current was not much lower than for the 28-week-old concrete measured in Method 3. These measurements during application of Method 4 have been referred to earlier in the section on current and temperature measurement during polarization. The probable explanation is that, initially, hydroxyl and calcium ions migrate into the specimen, increasing the conductivity of the pore water; the source of ions from the initially saturated calcium hydroxide solution is rapidly depleted and there is no further increase of current or decrease in resistance. The 68-week-old concrete in Method 4 shows an approximately 20 percent decrease in current and charge passed, and an approximately 21 percent increase in resistance. These results may be explained if it is assumed that there is a greater migration of ions from the specimen at the level of impermeability obtained at 68 weeks than diffusion into the samples from the saturated calcium hydroxide solution.

Correlations between initial current, charge passed, and resistivity—Plots of initial current versus charge passed and conductivity, and conductivity versus charge passed using Methods 1 and 3, are presented in Fig. 3 through 6.

Results of regression analysis of the data from Methods 1 and 3 are presented in Table 7. It can be seen from the figures that the data is well represented by straight lines. It may be observed that the changes in slope for charge passed versus conductivity, and charge passed versus initial current for the three cycles, are significant for both Methods 1 and 3. In addition, the changes observed are only slightly greater for those of Method 1. In the case of the conductivity versus initial current plot, the changes in slope between the three cycles are much smaller for both Methods 1 and 3.

Extended polarization period by Method 3 for 28-day-old concrete and chloride profiles through specimens

Four concrete specimens were subjected to polarization by Method 3 for 6, 12, 18, and 24 hr, respectively. Measure-

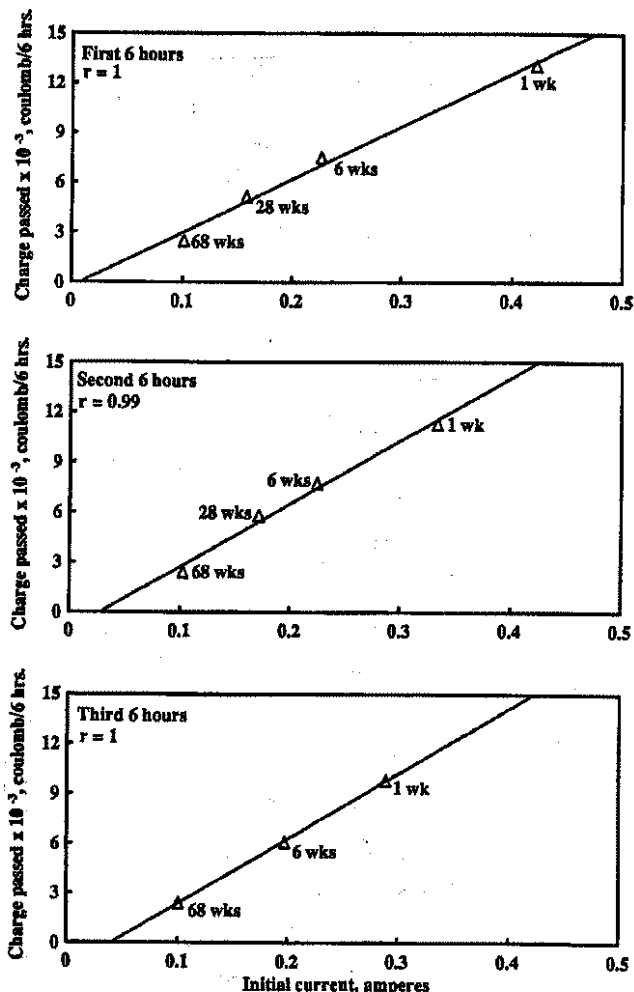


Fig. 3—Plot of initial current versus charge passed on polarization of four concretes by Method 1

ments of current, resistivity, and total charge passed were made every 3 hr of polarization at room temperature for the first 12 hr; readings were taken every 6 hr for the final 12 hr. Chloride profiles were measured through the four specimens. Current, resistivity, and charge passed are presented in Table 8 and chloride profiles are shown in Table 9. Chloride profiles were determined at depths of 0 to 2 mm (0 to 0.079 in.), 8 to 10 mm (0.32 to 0.39 in.), 24 to 26 mm (0.95 to 1.02 in.), and 48 to 50 mm (1.89 to 1.97 in.) from the cathodic side of the specimen. The average of three separate cores for each depth is summarized in Table 9.

Some of the data presented in Table 8 are plotted in Fig. 7 as initial current, resistivity, and charge passed versus total time. Except for Specimen A, the curves for the specimens display maxima in the resistivity-versus-time plot and minima in the charge passed and current-versus-time plots. The maxima and minima occur at between 6 and 11 hr for the three parameters. It may be observed in Table 9 that, at the surface of Specimen A (6 hr of polarization), adjacent to the anode (sample depth, 48 to 50 mm), the chloride concentration is 0.36 percent by weight of cement compared to 1.14, 0.72, and 1.16 for Specimens B, C, and D. This confirms that the maximum level of chloride absorption has not been attained in 6 hr of polarization, and therefore, beyond this point, the chloride concentration in the solution increases, re-

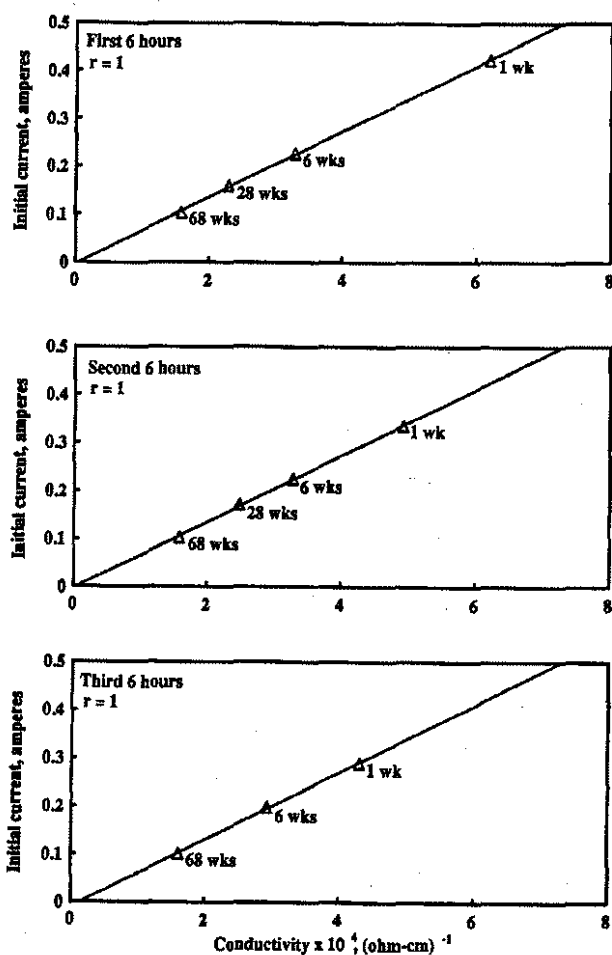


Fig. 4—Plot of conductivity versus initial current on polarization of four concretes by Method 1

sulting in a lower resistance and increase in current and total charge passed. Results in Table 8 show that changes in current and resistance can be substantial. For example, for Specimen D, a decrease of 27.6 percent in current occurs after 9 hr of voltage application, but an additional 9 hr results in an increase in current. Resistivity decreases of over 28 percent also occur after the maximum resistivity is attained.

DISCUSSION

It has been shown that polarization of relatively young concrete can cause considerable changes due to large increases in temperature that accelerate hydration. In the case of Method 3, this acceleration may be enhanced by the ingress of chloride ion into the pore solution. These phenomena are compounded because the resistance of the pore solution decreases with an increase of temperature. The net result for the four concretes was an increase in current during the three full 6-hr periods, regardless of the age of the concrete or the method used; the younger the concrete, the greater these effects on both the current and calculated charge passed.

Measurements of initial current and resistivity at room temperature can remove the effect of temperature on the re-

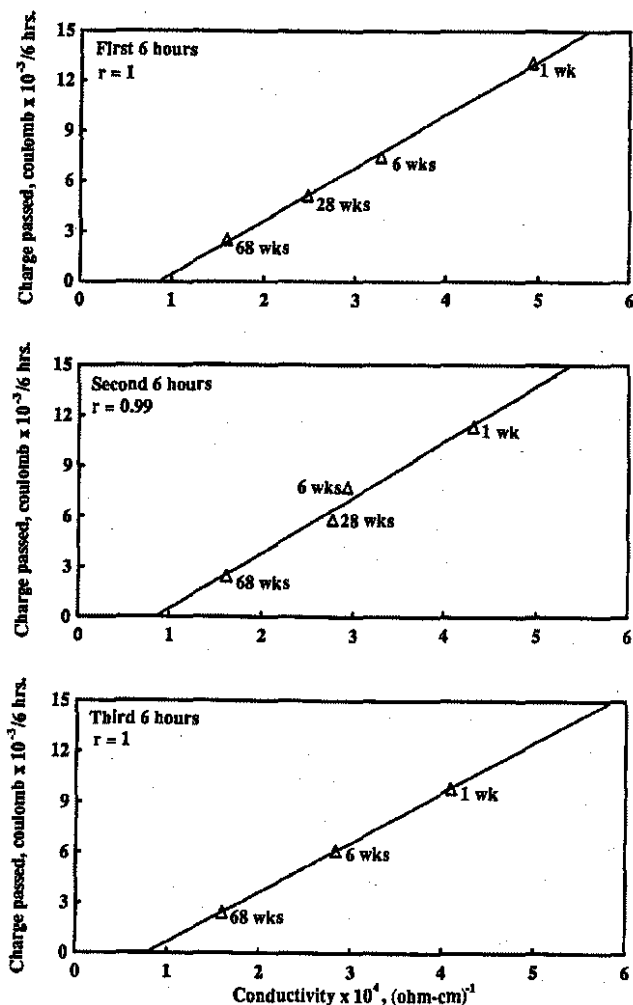


Fig. 5—Plot of conductivity versus charge passed on polarization of four concretes by Method 1

sult. It is clear from the plots presented in Fig. 2 that Methods 1 through 3 give similar results, that is, the 1-week-old concrete increases rapidly in resistivity, the 6-week-old concrete increases less rapidly, the 28-week-old concrete decreases in resistivity, while the 68-week-old concrete remains relatively constant. More extensive work with Method 3 on 28-day-old concrete confirms that ionic conductivity of the pore solution plays an important role (Fig. 7). The measurements of initial current, resistivity, and charge passed, as well as chloride profiles after 6, 12, 18, and 24 hr of polarization (Table 9), indicate that, after approximately 9 hr, the initial current and rate of charge passed increase, resistivity decreases, and chemical absorption of chloride into the specimen is complete. These observations imply that the concentration of chloride ion in the pore solution increases after the 9-hr period; before this, the concentration would be lower due to the chloride interaction with the cement. Consequently, the capacity of a specimen to pass charge can be increased by the addition of ions, whether chloride or hydroxyl.

The correlations of charged passed with conductivity and initial current show that, with the four concretes used, in the range of 11,000 to 1770 coulombs, resistivity measurements by AC impedance techniques or initial current measurement

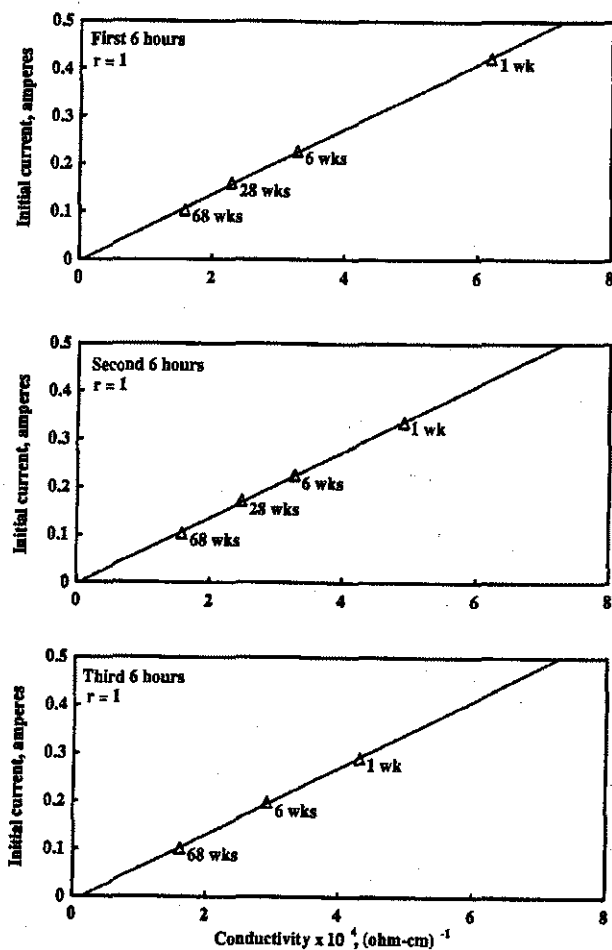


Fig. 4—Plot of conductivity versus initial current on polarization of four concretes by Method 1

sulting in a lower resistance and increase in current and total charge passed. Results in Table 8 show that changes in current and resistance can be substantial. For example, for Specimen D, a decrease of 27.6 percent in current occurs after 9 hr of voltage application, but an additional 9 hr results in an increase in current. Resistivity decreases of over 28 percent also occur after the maximum resistivity is attained.

DISCUSSION

It has been shown that polarization of relatively young concrete can cause considerable changes due to large increases in temperature that accelerate hydration. In the case of Method 3, this acceleration may be enhanced by the ingress of chloride ion into the pore solution. These phenomena are compounded because the resistance of the pore solution decreases with an increase of temperature. The net result for the four concretes was an increase in current during the three full 6-hr periods, regardless of the age of the concrete or the method used; the younger the concrete, the greater these effects on both the current and calculated charge passed.

Measurements of initial current and resistivity at room temperature can remove the effect of temperature on the re-

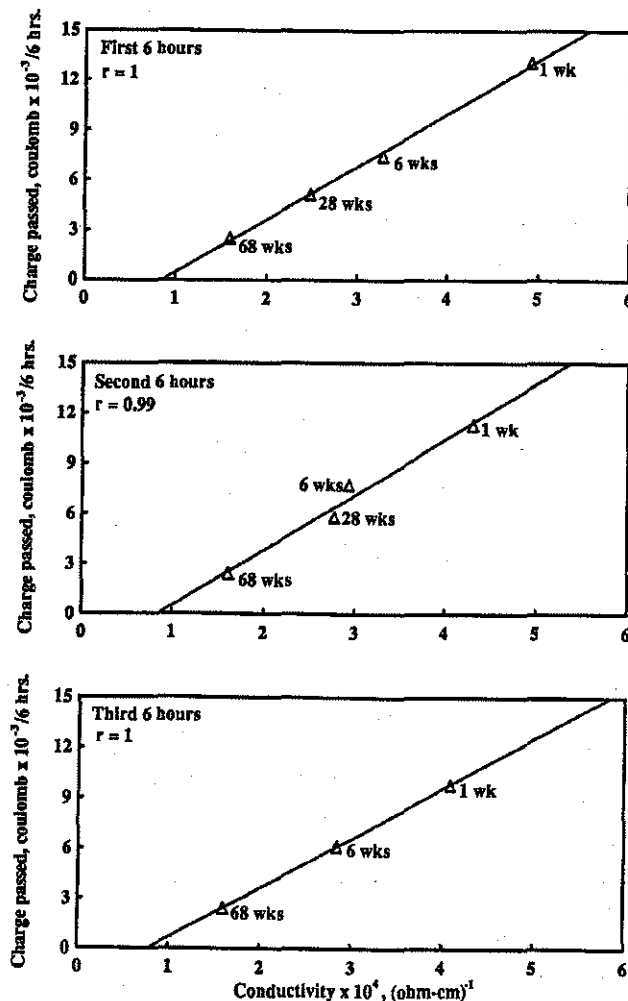


Fig. 5—Plot of conductivity versus charge passed on polarization of four concretes by Method 1

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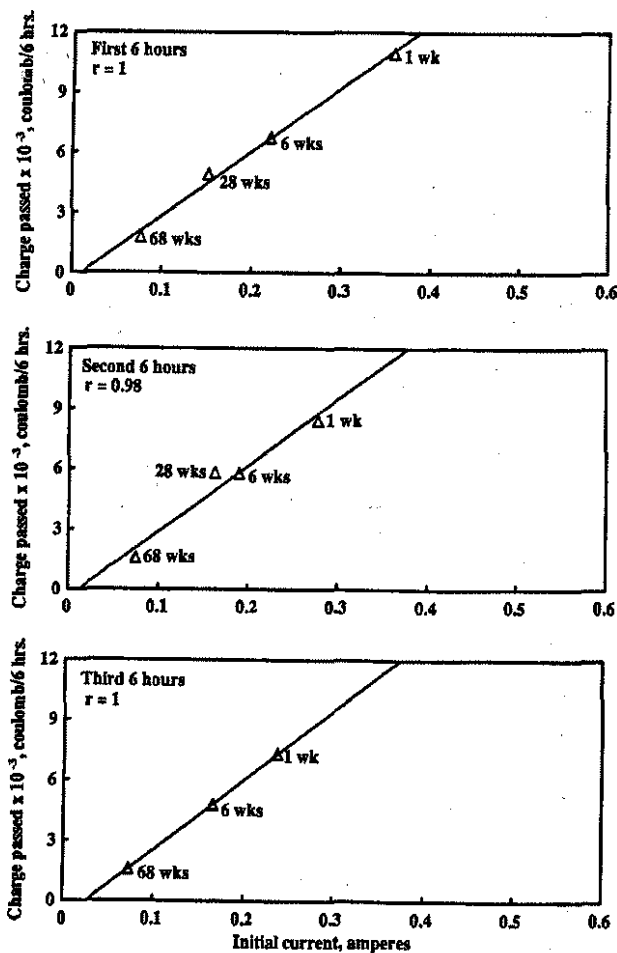


Fig. 6—Plot of initial current versus charge passed on polarization of four concretes by Method 3

would have provided the same ranking of concretes. This result is contrary to the findings of other researchers.¹⁸ Resistivity or current measurements take very little time to complete, do not change the nature of the specimen, and can be made without the use of relatively concentrated solutions. Correlations with the rapid chloride test should, however, be performed with lower permeability concretes and blended cement concretes.

CONCLUSIONS

1. Application of the rapid chloride permeability test induces change in the pore structure and resistivity of the concrete specimens tested.

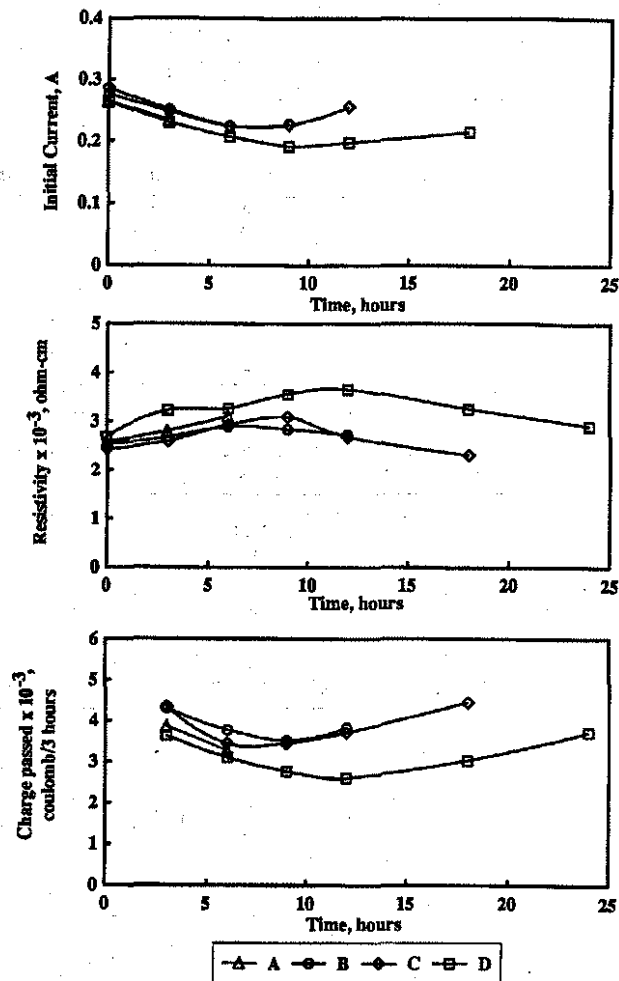


Fig. 7—Electrical properties as time function of 28-day-old concrete by Method 3 on 28-day-old concrete

2. During the 60 VDC polarization of older concrete, resistivity may decrease and initial current and charge passed increase due to an increase in concentration of ions in pore solution, resulting in overestimates of concrete permeability.

3. Good correlation between initial current and conductivity, initial current and charge passed, and conductivity and charge passed were obtained.

4. The same ranking of four concrete specimens (cured at 1, 6, 28, and 68 weeks) was obtained with sodium hydroxide or chloride in the electrode reservoirs. Chloride ion is not needed in the rapid permeability test.

5. Simple measurement of initial current or resistivity

Table 7—Slope and correlation coefficients for plots of Methods 1 and 3

		Method 1, hr			Method 3, hr		
		6	12	18	6	12	18
Charge passed versus conductivity	$m (x 10^7) r$	3.19	3.31	2.96	2.43	2.74	3.06
		1.00	1.00	1.00	1.00	0.99	1.00
Initial current versus conductivity	$m (x 10^2) r$	6.92	7.25	7.00	6.71	6.71	6.63
		1.00	0.99	1.00	1.00	1.00	1.00
Charge passed versus initial current	$m (x 10^4) r$	3.22	3.77	3.92	3.20	3.37	3.46
		1.00	0.99	1.00	1.00	0.98	1.00
Number of data points		4	4	3	4	4	3

Table 8—Current parameters as a function of time of polarization by Method 3 on 28-day-old concrete

Current								
Total time, hr	A		B		C		D	
	Current, amps	Change, percent	Current, amps	Change, percent	Current, amps	Change, percent	Current, amps	Change, percent
0	0.265	0.00	0.276	0.00	0.286	0.00	0.264	0.00
3	0.233	-11.86	0.247	-10.49	0.251	-12.30	0.230	-13.00
6	—	—	0.226	-18.26	0.223	-21.77	0.207	-21.73
9	—	—	0.227	-17.85	0.226	-20.90	0.191	-27.61
12	—	—	—	—	0.255	-10.79	0.197	-25.36
18	—	—	—	—	—	—	0.215	-18.66
24	—	—	—	—	—	—	—	—

Charge passed								
Total time, hr	Charge passed, coulombs/3 hr	Change, percent	Charge passed, coulombs/3 hr	Change, percent	Charge passed, coulombs/3 hr	Change, percent	Charge passed, coulombs/3 hr	Change, percent
0	—	—	—	—	—	—	—	—
3	3853	0.00	4297	0.00	4332	0.00	3626	0.00
6	3267	-15.21	3766	-12.36	3433	-20.75	3100	-14.51
9	—	—	3514	-18.22	3442	-20.54	2765	-23.75
12	—	—	3820	-11.10	3705	-14.47	2610	-28.02
18	—	—	—	—	4433	2.33	3042	-16.12
24	—	—	—	—	—	—	3716	2.48

Resistivity								
Total time, hr	Resistivity, ohm-cm	Change, percent	Resistivity, ohm-cm	Change, percent	Resistivity, ohm-cm	Change, percent	Resistivity, ohm-cm	Change, percent
0	2576	0.00	2527	0.00	2424	0.00	2674	0.00
3	2793	8.42	2667	5.54	2588	6.77	3214	20.19
6	3103	20.46	2879	13.93	2910	20.05	3257	21.80
9	—	—	2831	12.03	3079	27.02	3546	32.61
12	—	—	2712	1.69	2673	10.27	3644	36.28
18	—	—	—	—	2299	-5.16	3245	21.35
24	—	—	—	—	—	—	2901	8.49

Table 9—Chloride profiles for 28-day-old concrete specimens (A through D) after polarization by Method 3

Depth*	Chloride content, by weight of cement			
	A†	B‡	C§	D**
0 - 0.002 m (0 - 0.078 in.)	0.79	0.77	0.68	0.69
0.008 - 0.010 m (0.32 - 0.39 in.)	0.85	0.67	0.58	0.60
0.024 - 0.026 m (0.95 - 1.02 in.)	0.88	0.77	0.68	0.69
0.048 - 0.050 m (1.89 - 1.97 in.)	0.36	1.14	0.72	1.16

*Sample depth from negative electrode (NaCl), m.

†A = 06 hr of polarization.

‡B = 12 hr of polarization.

§C = 18 hr of polarization.

**D = 24 hr of polarization.

gives the same ranking for the four concrete specimens (cured at 1, 6, 28, and 68 weeks) tested, and can replace the rapid chloride test for those types of concrete.

6. Correlations with the rapid chloride test on blended cement concretes have not as yet been attempted.

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