Journal of Ferdowsi civil Engineering, Vol. 30, No. 2, 2018.

Modified Electrical Conductivity Test Method for Evaluation of Concrete Permeability

A. Pilvar[1*] A.A. Ramezanianpour[2]
H. Rajaie [3]

1-Introduction

It is widely known that the deterioration of concrete due to corrosion of reinforcement is one of the most significant durability problems that the construction industry is concerned with. Considering the importance of the chloride ion penetration mechanism, different types of tests have been employed up until now to measure the resistance of different types of concrete against chloride.

The electrical conductivity property of concrete was one of the properties of concrete that could be used to assess the ability of concrete against the penetration of chloride ions. The electrical properties of cement-based materials have been investigated for nearly a century. Theoretical and experimental studies indicated that there is a relationship between the electrical conductivity and the permeability of concrete. The electrical conductivity of concrete is the expression of the mobility of ions - containing chloride ions - in pore solution of the the concrete. Hence, it was expected that there was a logical relation between electrical conductivity and permeability of the concrete.

However, there were limitations in the relationship between the conductivity and the permeability of concrete. Conductivity of the concrete samples depends on both properties of the capillary pore structure and the pore solution conductivity. However, by saturating the concrete specimens with highly conductive solution, the variability of pore solution becomes much less significant.

In this contribution, based on fundamental electrochemical principles, a modification on electrical conductivity test is proposed. The results of this test are independent of the pore solution conductivity of the concrete. This paper deals with the electrochemical principles that led to the development of the modification on electrical conductivity test. It also describes the test method.

2. Test method

The apparatus are the same as described in Test Method ASTM C1760. They consist of two 250 ml cells, contiguous to a central part, which contain the concrete sample. Both cells are tied to the central section, thus they compress the silicone rubber collar and clamp the sample. Each cell contains a 5 M NaCl solution. A potential difference of 10 volts is applied for passing a direct current through the sample via the stainless steel anode and cathode. A data logger reads the flowing current accurately.

The apparatus is designed for concrete or mortar samples of 100 mm diameter and 25 mm thickness. Typically, the samples are sliced from cast cylinders or drilled cores. Samples are kept in the oven at 50°C for 7 days for being dried. After that, they are vacuum dried for 3 hours, then they are saturated in vacuum in a 5 M NaCl solution for 2 hours, and they are left to soak in the solution for an additional 18 hours.

After setting up the cells, the circuit is arranged and the current is measured for 1 min after the voltage (10 V) is first applied. This current is recorded as the output of the experiment. For calculating the conductivity of each sample using the applied potential difference, the current is measured and the dimensions of the sample, equation 1 have been used.

$$\sigma = \frac{i}{V} \cdot \frac{t}{A} \quad (1)$$

where σ is the conductivity of the sample [mS/cm], i is the electric current [mA], V is the potential difference [V], t is the thickness of the sample [cm], and A is the cross sectional area of the sample [cm^2].

3. Experimental programs

In order to examine the performance of the instrument built for measuring the permeability of concrete against chloride ions, 20 different concrete mixtures were used, including ordinary concrete, concrete containing silica fume and concrete containing calcined perlite powder. The summary of mixture proportions are shown in Table 1.

ASTM C150 type I Portland cement was used in all the concrete mixtures. Two pozzolans used in this work, were silica fume (SF) and calcined perlite powder (CPP).

For all mixed designs, coarse aggregates were crushed calcareous stone with the maximum size of 19 mm and fine aggregates were natural sand. Potable water was used for casting and curing all concrete specimens. Also, the Polycarboxylate Ether (PCE) based on superplasticizer was employed to achieve relatively constant workability.

4. Results and discussion

In addition to the method developed in this study, which is hereafter referred to as the MBCT (Modified Bulk Conductivity Test), two standard test methods

[1]* Corresponding Author, Ph.D., Department of Civil Engineering, Toos University, Mashhad, Iran.
Email: amir63p@aut.ac.ir
[2] Ph.D., Department of Civil & Environmental Engineering, Amirkabir University of Technology, Tehran, Iran
[3] Ph.D., Concrete Technology and Durability Research Center (CTDRc), Amirkabir University of Technology, Tehran, Iran.

RCPT (ASTM, 2012a) and bulk conductivity (BCT) (ASTM, 2012b), have also been applied to all of the samples. The average of three test results is used to minimize the discrepancy of the results. The results are shown in Table 2.

Table 1. Mix proportion of concretes

No.	Mix	Binder (kg/m^3)	w/b	Supplementary Material	
				Type	Percentage
1	SF404500	400	0.45	SF	0
2	SF403500	400	0.35	SF	0
3	SF354500	350	0.45	SF	0
4	SF353500	350	0.35	SF	0
5	SF404507	400	0.45	SF	7.5
6	SF403507	400	0.35	SF	7.5
7	SF354507	350	0.45	SF	7.5
8	SF353507	350	0.35	SF	7.5
9	SF404515	400	0.45	SF	15
10	SF403515	400	0.35	SF	15
11	SF354515	350	0.45	SF	15
12	SF353515	350	0.35	SF	15
13	Pe304500	300	0.45	CPP	0
14	Pe304510	300	0.45	CPP	10
15	Pe304520	300	0.45	CPP	20
16	Pe304530	300	0.45	CPP	30
17	Pe303500	300	0.35	CPP	0
18	Pe303510	300	0.35	CPP	10
19	Pe303520	300	0.35	CPP	20
20	Pe303530	300	0.35	CPP	30

As it is shown in Table 2, at constant water to binder ratio and cement content, replacing cement with silica fume will remarkably decrease the total passed charge in RCPT and the conductivity of concrete samples. These can be justified by noting that pozzolanic reactions proliferate the tortuosity in the structure of capillary pores and further condenses the pore structure. Furthermore, as the concentration of OH^- ions diminishes in most of these reactions, the conductivity of the pore solution diminishes substantially. As a result of these two phenomena, as well as dilution, the conductivity of concrete substantially decreases.

However, the issue relating to reduction in conductivity has been moderated in the MBCT method. This can be ascribed to the saturation of the samples with 5 M NaCl solutions and the uniformity of the pore solutions conductivity of the different concrete samples. Therefore, it can be argued that this method is less sensitive towards the variations in the pore solution conductivity in different concretes.

Replacing cement with CPP of different levels leads to a decrease in the RCPT and bulk conductivity up to half at the age of 28 days. Probably, the dilution effect and pozzolanic reactions are the main reasons. Furthermore, at the age of 91 days, this reduction is more sharply to less than one fifth in comparison with the control mixtures. It seems that, in addition to the dilution effect, the main reason of this great reduction is the pozzolanic reaction which can result in the reduction of the conductivity of the pore solution.

Table 2: Tests results

No.	Mix	BCT (mS/cm)		RCPT (columbs)		MBCT (mS/cm)	
		28 days	91 days	28 days	91 days	28 days	91 days
1	SF404500	0.254	0.183	5706	4460	1.09	0.88
2	SF403500	0.172	0.119	3807	2556	0.72	0.59
3	SF354500	0.218	0.149	4802	3335	0.98	0.82
4	SF353500	0.150	0.088	3158	1944	0.62	0.43
5	SF404507	0.084	0.047	1918	988	0.61	0.47
6	SF403507	0.060	0.030	1262	629	0.40	0.30
7	SF354507	0.083	0.043	1772	958	0.57	0.44
8	SF353507	0.059	0.027	1243	551	0.36	0.23
9	SF404515	0.056	0.019	1143	417	0.50	0.40
10	SF403515	0.041	0.015	796	319	0.33	0.27
11	SF354515	0.049	0.018	1062	396	0.46	0.35
12	SF353515	0.036	0.014	750	294	0.30	0.19
13	Pe304500	0.303	0.202	6769	5472	1.57	1.40
14	Pe304510	0.249	0.121	5796	2618	1.50	1.20
15	Pe304520	0.207	0.072	4374	1485	1.31	1.03
16	Pe304530	0.148	0.050	3129	1042	1.25	0.81
17	Pe303500	0.179	0.131	3922	3159	1.24	1.09
18	Pe303510	0.162	0.082	3550	2010	1.20	0.95
19	Pe303520	0.141	0.052	3078	1120	1.04	0.83
20	Pe303530	0.125	0.044	2692	810	0.99	0.65

5. Conclusion

Based on the experimental and analytical results, the following conclusions are drawn:

1. The results of the three tests illustrated that applying SF and CPP reduces the chloride permeability of concrete.
2. Due to the consumption of OH^- ions that ensue in the pozzolanic reactions and consequently the substantial reduction in the conductivity of the pore solution, the permeability indicator of the concrete samples incorporating SF and CPP exhibit a substantial reduction when compared to control samples for BCT and RCPT methods.
3. For concretes containing SF and CPP, the MBCT is less sensitive towards the variations in the pore solution conductivity in comparison with RCPT and BCT.