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Evaluating concrete durability using simple non–destructive test towards performance–based specifications

Abstract

Concrete Durability is considered an essential characteristic of concrete structures exposed to the aggressive environment. Evaluating concrete durability using traditional laboratory tests is time–consuming and elaborate. Also, using non–destructive tests (NDT) requires the use of sophisticated and costly tests. Chloride–induced corrosion is the most deterioration mechanism worldwide. Concrete capability to resist the penetration of chloride ion can be evaluated by the rapid chloride ion penetration test (RCPT) as per ASTM C1202. This study investigates the use of a simple, rapid and economic NDT (i.e., surface resistivity test) to evaluate the concrete resistance to chloride ion penetration. Test results showed that surface resistivity results correlate very well with chloride ion penetration results. Also, surface resistivity can predict a wide range of RCPT values with very good accuracy. That will help practitioners to quickly, efficiently and economically evaluate concrete durability using a simple NDT. That will help to move towards performance–based specifications and improve quality control of concrete during construction.

Keywords: durability, performance–based specifications, surface resistivity

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Abbreviations: CWP, Ceramic waste powder; NDT, non–destructive tests; RCP, rapid chloride penetration test; SCC, self–compacted concrete; SCM, supplementary cementing material; W/C, water to cement ratio

Introduction

Concrete durability is defined as the resistance of concrete to deterioration when exposed to the aggressive environment. Design codes consider durability in a structural design by setting limits to minimum compressive strength, maximum w/c ratio, minimum cement content and minimum concrete cover. These design codes do not specify methods for assessing durability performance of concrete structures. A couple of studies were conducted on the performance–based specification for cast–in–place concrete.[1,2] It was concluded that current codes and practice do not provide sufficient controlled durability and performance–based methods to be used. Current standard tests to assess concrete durability are both time–consuming and elaborate. Therefore, a simple, quick and non–expensive test is needed to evaluate concrete durability during construction. The use of non–destructive tests (NDT) could be the answer to this problem. One of the significant durability problems is the chloride–induced corrosion and how good the concrete is in protecting the embedded reinforcement. The concrete ability to resist chloride ion penetration can be evaluated through different laboratory tests such as chloride ion diffusion and rapid chloride ion migration (i.e., rapid chloride ion penetration test RCPT ASTM C1202[3]). Concrete's electrical resistivity is a material property that defines the resistance against the flow of electrical current. The electrical resistivity is a simple, rapid and a non–destructive test that can be used for evaluating the resistance of concrete to chloride ion penetration/diffusion. The test can be used during construction as a way for quality control. Extensive research and development on electrical resistivity measurement techniques as a non–destructive test have been evaluated.[4] There are two standards for electrical resistivity measurement; bulk electrical resistivity according to ASTM C1760[5] and surface resistivity according to AASHTO TP 95–11.[6] Studies showed that there is a strong direct linear correlation between these two methods of resistivity measurements.[4] Investigations also showed that electrical resistivity could be correlated to chloride diffusivity.[4,7] Chloride diffusion tests require several days to be conducted. On the other hand, RCPT test requires less than three days conducting including specimen's preparation time. On the other hand, surface resistivity test only needs few minutes to be conducted. Therefore, surface resistivity test has an excellent potential to be used as a simple, rapid and non–expensive test to evaluate concrete durability. In this study, surface electrical resistivity is correlated to RCPT values to establish the relationship and how good it is. In the study, the surface resistivity was measured using Wenner four probe equipment as shown in Figure 1A. RCPT was conducted as per ASTM C1202[3] as shown in Figure 1B. Each test was conducted on three specimens. The study was conducted on different concrete mixtures. The mixtures included conventional vibrated concrete and self–compacted concrete (SCC). The study intended to have a wide range of primary mixture's ingredients such as the cement content, the water–to–cement ratio (w/c), the inclusion of admixtures, and the inclusion of ceramic waste powder (CWP) as supplementary cementing material (SCM). The cement content ranged from 350 to 525 kg/m^3, the (w/c) ranged from 0.34 to 0.61, the used of admixtures were Type G and II, and the (CWP) ranged from 20% up to 60% replacement of cement by mass. The compressive strength ranged from 25 to 80 MPa. The tests were conducted at two different ages 28 days and 90 days of age. There were 42 average results of surface resistivity and RCPT values. The used mixtures were selected to provide a wide range of RCPT and surface resistivity values. The

RCPT ranged from below 100 up to 5000 coulombs, while surface resistivity values ranged from 5 to 400 kΩ.cm. That represented a wide range of concrete quality concerning resistance to chloride ion penetration and corrosion protection as per Table 1 and Table 2.

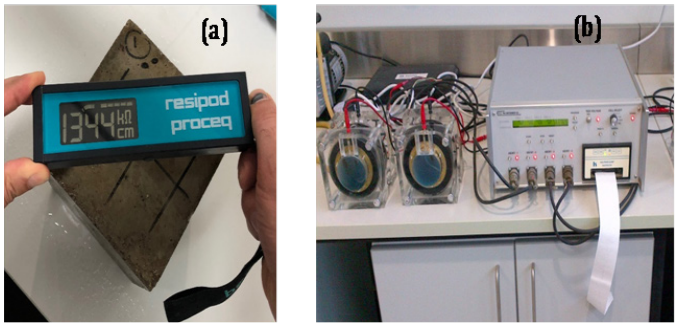

Figure 1 Conducted tests;
a. Surface resistivity test
b. RCPT.

Table 1 Classification of chloride ion penetrability3

Charge passed (coulombs)	Chloride ion penetrability
>4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very Low
<100	Negligible

Figure 2 shows the relation between surface resistivity and RCPT results. The relationship between both results showed very good correlation with the R^2 value of 0.952. Figure 3 shows the very good relationship between the measured RCPT results and predicted RCPT values. The relationships show that surface resistivity can accurately predict the concrete's resistance to chloride ion penetration. Also, the prediction can be used for a wide range of concrete quality. According to the developed relationship, Table 3 shows the correlation between surface resistivity and chloride ion penetrability classification. Therefore, surface resistivity test can be used as a quick, not costly and efficient method to evaluate concrete durability regarding chloride ion penetration and corrosion resistance.

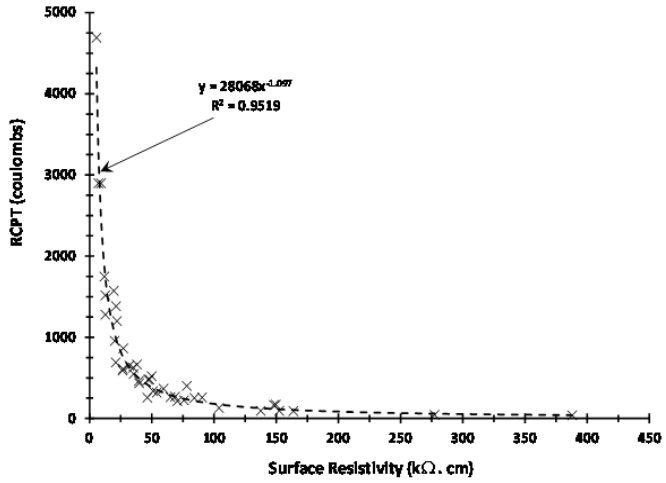

Figure 2 Relation between surface resistivity and RCPT results.

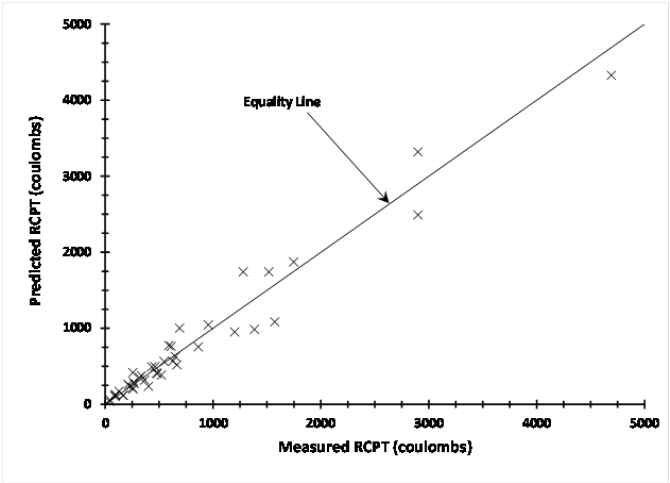

Figure 3 Relation between measured and predicted RCPT values.

Table 2 Relation between concrete resistivity and corrosion protection8

Resistivity (kΩ . cm)	Corrosion protection
<5	Low
5 to 10	Low to Moderate
10 to 20	High
>20	Very High

Table 3 Correlation between surface resistivity and chloride ion penetrability classification

Charge passed (coulombs)	Chloride ion penetrability	Surface resistivity (kΩ . cm)
>4000	High	<6
2000 to 4000	Moderate	6 to 11
1000 to 2000	Low	11 to 20
100 to 1000	Very Low	20 to 170
<100	Negligible	>170

Conclusion

Laboratory tests to evaluate concrete resistance to chloride ion penetration are length and not economic. Surface electrical resistivity correlates well with a wide range of RCPT values Surface resistivity can be used as a quick, economical and efficient NDT to evaluate concrete durability with respect to chloride ion penetration. Surface resistivity test can be easily used to improve quality control of concrete during construction to meet required performance–based criteria. The surface resistivity test can be used as a tool to provide sufficient controlled durability and performance–based specifications.

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None

Conflict of interest

The authors declare no conflict of interest.

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