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Influence of parameters on surface resistivity of concrete

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ABSTRACT

Several studies have investigated different techniques for measuring electrical properties of concrete which is an important physical property related to chloride induced corrosion in reinforced concrete structures. This research examined the surface resistivity (SR) and the bulk electrical resistivity (BR) of concrete cylinders for several ternary mixtures at different testing ages. In addition, this study evaluated the influence of various significant parameters namely geometric size, probe spacing, replacement levels of silica fume and metakaolin in ternary based cementitious mixtures on the SR of concrete. New recommendation has been proposed for chloride ion permeability classification on the basis of electrical resistivity and compared with widely used Florida and Louisiana DOT classification. Overall, this study will enable researchers and state highway agencies to use non-destructive SR and BR measurement technique as a potential tool to evaluate ternary based high performance concrete (HPC) mixtures and predict the corrosion rate.

1. Introduction

Over the last two decades, different techniques have been proposed to examine the electrical properties of concrete [1–4]. These experiments are easy to perform due to their straightforward working procedure. One of the more established destructive test methods that are currently performed based on electrical concepts is the Rapid Chloride Permeability Test (RCPT) [5–6]. This test method involves placing a saturated concrete specimen, typically 102-mm diameter and 51-mm thick, between electrodes in different solutions and integrating the charge that is passed over a six hour testing period [5]. While this test is still widely used, there are a few shortcomings that have been pointed out [7,8]. One of the existing non-destructive methods of determination of concrete resistance to the chloride ion penetration is the electrical resistivity by Wenner probe device. The Florida Department of Transportation has developed a method to standardize procedures for collection of resistivity readings [9]. Experimentation using the Wenner device on 529 sample sets was conducted by Kessler et al. at the Florida Department of Transportation to investigate whether resistivity can be used as a quality control measure in place of the RCPT6 [10]. Tikalsky et al. completed a recent study on different binary and ternary based HPC mixtures electrical resistivity testing and found that resistivity data is well correlated with RCPT data for different binary and ternary based HPC mixtures [11]. Marriaga et al. studied the reliability of the RCPT and resistivity test on the basis of chloride resistance of Ground Granulated Blast Furnace Slag (GGBFS) mixtures with different levels of cement replacements. They established that the electrical resistivity and the total charge passed is an indirect measure of the chloride penetration suitable for both OPC and GGBS mixtures [12]. Rupnow et al. recently showed that the better precision of Wenner probe resistivity meter from their experimental investigation of single laboratory and multi laboratory measurements and surface resistivity test shows lower variability than rapid chloride permeability test with different HPC mixtures [13]. Paredes et al. conducted rigorous round robin program to document the repeatability and reproducibility of surface measurements data on 12 different PCC mixtures in several laboratories [14]. Darren et al. established effectiveness of electrical resistivity technique for HPC to obtain a relationship with chloride diffusivity in order to evaluate the quality of the concrete. Their findings showed a high correlation coefficient in the range between 0.94 and 0.99, representing the suitability of using electrical resistivity technique to evaluate the quality control of high performance concrete and prediction of corrosion rate [15]. Another possible method is to measure electrical resistance of concrete cylinder by using plate electrodes on the end of the sample [16,17]. This test can be performed by utilizing conductive medium and needs to be remembered that surface finish needs to be flat as much as possible for proper contact pressure and sponges were used between sample and plates to obtain better contact. Recently, Spragg et al. analyzed variability studies on 12 different cementitious mixtures for BR and SR and correlation

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was established at testing ages of 28,56 and 91 days. Additionally, the effect of electrode resistance was discussed. It was noticed that the effect is not significant on high resistivity concrete [18].

The research presented here focused on evaluation of the BR and the SR of various ternary based cementitious mixtures by two different instruments on two different sizes of cylinders. Influence of variation of replacement level of metakaolin and silica fume (3–12%) on the BR and the SR was also investigated from 7 to 91 days. The main aim of this research is to show the SR measurement as a promising non-destructive quality control tool for durability measurement and also as an alternative solution of the RCPT and other long term migration testing to evaluate corrosion activity in a quicker and simpler way. The other purpose of this study is to identify multiple design solutions in terms of durability that result in long-life of reinforced concrete bridge decks throughout the nation.

2. Materials

Twenty-three different types of ternary and binary cementitious mixtures including the control mixture of 100% portland cement with a water/cementitious materials ratio of 0.44 were designed to provide a wide range of values for this experimental program. This water-cementitious materials ratio is typical for exposed bridge deck and substructure concrete. All mixtures contained 335 kg/m^3 of cementitious material with a Coarse Aggregate Factor (CAF) of 0.67. Limestone coarse aggregate of size (75 mm) meeting ASTM C33 No.67 gradation and ASTM C33 silica sand were used. All supplementary cement materials (SCMs) were replaced by mass. Tests were performed on mixtures using:

- Type II–V cement (TII–V)
- Ground granulated blast furnace slag of grade 120 (G120S)
- Class F fly Ash (F)
- Silica fume (SF)
- Metakaolin (M)

Due to sulfate attack problems in California, it is mandatory to use Type II–V cement instead of Type I cement. The selection of mixture design was based on concrete mixtures meeting basic technical properties and also representing a diverse range of solutions to investigate long term durability. The basic mixture parameters were coded into the label names of the mixtures with percentage of each cementitious material, e.g. 75TII-–V/20F/5SF means 75% Type II–V Cement, 20% Class F fly ash and 5% Silica Fume. A high-range water reducing admixture (Glenium 7700) and an air entraining agent (MBVR AE90) were used to meet better workability and durability performance specifications. All mixtures were cast according to ASTM C192 practice. Three cylinders of 100 mm × 200 mm and two cylinders of 150 mm × 300 mm were prepared for testing the SR and the BR resistivity measurement at ages of 7, 14, 28, 56 and 91 days. The cylinders were demolded after 24 ± 2 h and they were continuously cured in lime water tank.

3. Experimental work

3.1. 4-point Wenner probe for surface electrical resistivity measurement

The SR measurement was performed by commercially available non-destructive Wenner 4 probe Surface Resistivity (SR) meter, manufactured by Proceq. Florida testing methodology was implemented for the SR measurements at 7, 14, 28, 56, and 91 days for 100 mm × 200 mm and 150 mm × 300 mm cylinders except for curing condition and probe spacing of the Wenner probe instrument. A multiplier of 1.1 was used for electrical resistivity data as suggested by AASHTO TP-95 for lime water curing condition. All cylinders were removed from lime water tank on the specified testing days and tested at surface saturated dry (SSD) condition at 23° ± 2 °C by 4 point Wenner probe meter. Readings were taken two times with 0, 90, 180 and 270 degree angles of circular face of each concrete cylinder. Data was collected by Wenner probe meter using a probe spacing of 50 mm, instead of 38 mm as recommended by FDOT. The whole experimental process was easy to set up and it took less than thirty minutes to complete. Three 100 mm × 200 mm and two 150 mm × 300 mm cylinders were tested for each concrete mixture for the SR measurement. The equipment works on low frequency alternating current which is flowing between the outer electrodes and measures the potential difference between two inner electrodes. Assuming that the concrete cylinder has homogeneous semi-infinite geometry (the dimensions of the element are exceptionally large in comparison of the probe spacing), and the probe depth is far less than the probe spacing, the concrete cylinder resistivity (ρ) can be computed as:

$$\rho_1 = 2\pi a \frac{V}{I} = 2\pi a R_1 \quad (1)$$

where, a is the probe spacing (cm); V is the applied voltage (Volt); I is the current (A); and R_1 is the surface resistance (Ohm). Fig. 1 shows Wenner probe instrument with its working methodology.

3.2. Merlin meter for bulk resistivity measurement

Merlin meter was utilized to measure the BR of concrete specimens of 100 mm × 200 mm size. It is another non-destructive instrument and manufactured by Germann Instruments. At the testing ages of 7, 14, 28, 56, and 91 days, the concrete cylinders were removed from lime water tank and tested at SSD condition. Similar to the SR, a multiplier of 1.1 is also applied for all BR data due to lime water curing condition. For the BR measurement, readings were obtained two times by swapping two ends of the concrete specimen within the clamp attached to the electrode and the data logger attached to the computer directly records the bulk conductivity or its inverse the BR. Once the measurement is taken in first few seconds, the BR reading appears unstable and increases at faster rate. It usually takes one or two minutes for the data to become stable and then it is recorded. While conducting the experiment, it is important to check and calibrate the meter by the verification cylinder provided by the manufacturer.

An alternating current source is used to apply the current at a fixed frequency of 325 Hz through the specimen. The instrument is set up with a voltmeter to measure the voltage drop V, across the specimen and an ammeter to measure the current I. BR is computed using Ohm's law from voltage and current passed as follows:

$$\rho = \frac{VA}{IL} = R\frac{A}{L} \quad (2)$$

where ρ is the bulk electrical resistivity (Kohm cm), R is resistance (Kohm), I is current (A), L is length of the specimen (cm), V is the voltage drop (Volt) and A is cross section area of the specimen (cm^2). Fig. 2 shows schematic diagram of fundamental physics involved for measurement of the BR.

Here, BR data is involved in order to show that SR can be used as precise and consistent as BR by means of comparing between the corrected SR using geometric correction factor and actual bulk resistivity, which is BR. Thus SR can be used for the analysis of durability indicated criteria in order to show the variation of the resistivity in different mixtures.