Overview on the *B* Conducting Filler in Electrical Properties of Composite Concrete

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Abstract: The durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other deterioration process to retain its original form, quality and serviceability when exposed to harsh environment. To a large extent, it is commonly accepted that concrete durability is governed by concrete's resistance to the penetration of aggressive media. This media may be present in a liquid or gaseous state and that may be transported by various mechanisms such as permeation, diffusion, absorption, capillary suction, and combinations of the items just mentioned.

Keywords: Composite Concrete, Concrete Durability, Electrical Resistivity, Electrical Conductivity

I Introduction

Consequently, the transport of ions through microstructure of concrete plays an important role in the control of concrete durability. When ions are charged, then it is the concrete's ability to withstand transfer of charged ions which is highly dependent upon its electrical resistivity. Hence, for concrete in service, a combined action of various media may prevail and mixed modes of transport processes occur. Moreover, there are correlations between transport parameters of concrete and the following durability characteristics: carbonation, sulphate attack, alkali-aggregate reaction, frost resistance, leaching, soft water attack, acid attack, abrasion, chloride ingress, and reinforcement corrosion.

Over the last few decades, a great deal of attention has been paid to research and development of electrical resistivity measurement techniques as a non-destructive technique (NDT) to evaluate the durability of concrete structures. This method is becoming more popular especially for field evaluations due to its simplicity, rapidness, and cost during test conduction. However, the inclusion of these methods into the standards and guidelines is quite slow. Electrical resistivity has been standardized in 2012 by ASTM C1760 to measure the concrete bulk resistivity.

Electrical resistivity is a material property that can be used for various purposes, one of which is to identify early age characteristics of fresh concrete. When the fresh concrete sets and hardens, depreciation (discontinuity) of the capillary pore space leads to an increase in its electrical resistivity. Since electrical current is conveyed by dissolved charged ions flowing into the concrete pore solution, it is a good indicator of concrete pore structures. This pore structure formation at early-ages can define the long-term durability of concrete. In addition, the tensile strength of cementitious materials at early-ages is low and the material is prone to cracking. This initial cracking also serves as a pathway for deleterious materials to ingress into the matrix. This cracking can also be captured by resistivity measurements and thus helps predict the long-term durability of concrete. In addition, electrical resistivity can be used as an index to determine the moisture content and the connectivity of the micro pores in the concrete. Several researchers attempted to characterize the effects of various parameters on electrical resistivity measurements.

The electrical conductivity of a particular material is its capability to transfer ions under an electric field. Electrical resistivity is the inverse of electrical conductivity. The electrical resistivity is the ratio of the applied potential difference to the current developed. The value is multiplied by a constant, cell constant. The resistivity greatly varies based on the material property. Resistivity of a material is not influenced by its geometric ties. Practically electric resistance is found using standard testing methods and equipments. The value obtained multiplied with the cell constant yields the electrical resistivity of the material. The cell constant varies with the testing equipment. The electrical resistivity of concrete ranges over greater extents. Wet concrete behaves as a semiconductor, with resistivity in the range of 105 ohm-mm. whereas dry concrete has resistivity in the range of 1012 ohm-mm. Hence oven dry concrete acts as an insulator. The variation in the measured electrical resistivity in wet and dry concrete can be interpreted to find that the electrical conductivity of concrete is a significant effect of the evaporable water present in it. Therefore it can be expected that conductivity increases with increase in ion transfer, which is with increase in water cement ratio of concrete.

Transfer of ions has to take place significantly for the conductance of electricity in concrete, which can happen only when a porous microstructure with great amount of interconnections are present. Such a concrete will be highly permeable leading to effective transfer of ions. The salinity of the water to be used for mixing concrete greatly influences the electrical conductivity with high water cement ratios. The resistivity is quite small in high strength concrete. The electrical resistivity of concrete is also greatly influenced by aging of concrete, at least for the initial period of curing.

The relation between the volume fraction occupied by water and the conductivity of concrete can be obtained from the laws of conductivity. However, for the usual concrete mixes, the water cement ratio varies little for a given workability and grading. Thus the electrical conductivity is influenced by the cement used, because the chemical composition of cement administers the quantity of ions present in the water. Most of the admixtures used do not increase the electrical conductivity of concrete significantly.

II Electrical Resistivity

Electrical resistivity measurement techniques are becoming popular among researchers and scholars for the quality control and durability assessment of concrete (for example, refer to References 6 and 7). The adoption of these techniques into standards and guidelines has been rather slow, with only surface electrical resistivity adopted as a test method by the American Association of State Highway and Transportation Officials (AASHTO TP 958).

The Concepts

Durability of concrete depends largely on the properties of its microstructure, such as pore size distribution and the shape of the interconnections (that is, tortuosity). A finer pore network, with less connectivity, leads to lower permeability. A porous microstructure with larger degree of interconnections, on the other hand, results in higher permeability and reduced durability in general. The principal idea behind most electrical resistivity techniques is to somehow quantify the conductive properties of the microstructure of concrete. Overall, the electrical resistivity of concrete can be described as the ability of concrete to withstand the transfer of ions subjected to an electrical field. In this context, resistivity measurement can be used to assess the size and extent of the interconnectivity of pores. Resistivity r is an inherent characteristic of a material, and is independent of the geometry of the sample. Equation 1 describes the relationship between the resistivity and resistance:

$$\rho = k.R \tag{1}$$

where R is the resistance of concrete; and k is a geometrical factor which depends on the size and shape of the sample as well as the distance between the probes on the testing device. In practice, electrical resistance is directly measured by the testing device and resistivity is calculated from Equation 1.

III Measurement Techniques for Electrical Resistivity

3.1 Wenner Probe Method

This method is one of the widely accepted methods in which, the surface electrical resistivity of concrete is found. The experimental setup consists of four equally spaced electrodes, placed normal to the curved surface of the cylindrical concrete specimen with necessary electrical connections to read out the input current and the potential drop (Figure 1).

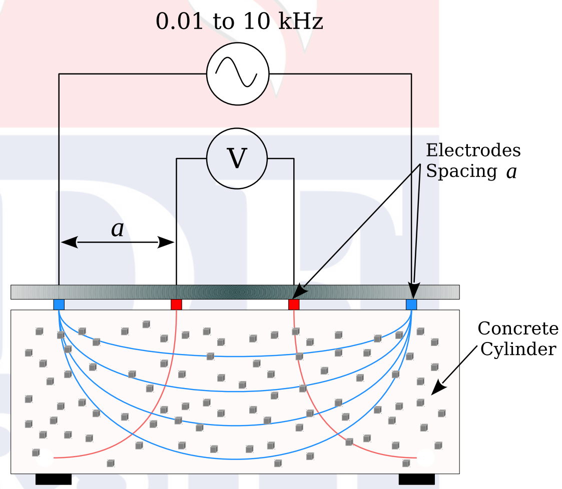

Figure 1: Experiment Setup Wenner Probe Method

Unlike the two point uniaxial method where current and voltage drop are measured from the same set of electrodes, this method applies current through the two exterior electrodes and measures the potential difference between the two inner electrodes.

3.2 Electrical Conductivity and Corrosion Monitoring

Feliu have found a linear relation between electrical conductivity and reinforcement corrosion in concrete. The theoretical explanation is the fact that with corrosion is an effect of chemical reaction between the ferrous of the reinforcement and oxygen of atmosphere or water in concrete. On corrosion ferrous oxide, rust forms over the reinforcement. Rust is an excellent conductor of electricity. Hence there exists a linear relation between the electrical conductance and corrosion rate of concrete. With increase in corrosion, the rebar swell leading to formation of cracks and more vulnerable to corrosion. Hence electrical conductance increases with rate of corrosion.

3.3 Real-Time Temperature and Maturity Monitoring of Concrete

SmartRock2™ is a rugged waterproof wireless sensor that allows real-time temperature and maturity monitoring of concrete as shown in Figure 2. The sensor is placed in the concrete formwork (installed on the rebar) before pouring. Using the SmartRock2™ app you can view the temperature and resulting concrete strength in real-time.

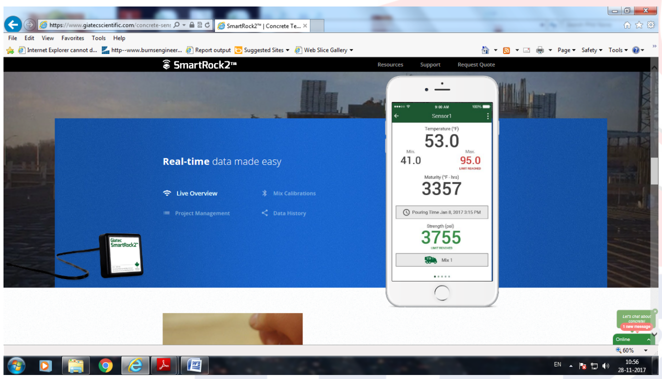

Figure 2: SmartRock2™

IV Applications

Conductive Concrete received considerable attention. Conductive concrete was investigated using different types of conductive fillers or phases in the form of particles or fibers which were included into the cement matrix. Examples of the conductive fillers or phases used are fibbers of graphite, carbon, steel, steel shavings, graphite powder, steel wool, carbon black powder and carbon black nanoparticles, carbon nano-fibers and nanotubes. The main conclusions from the different investigations were that the size and dispersion of the filler are more important than its conductivity and that the volume or quantity of the filler affected the concrete conductivity. Also, it was concluded that the concrete conductivity could be enhanced even by using fillers in low volume fraction. A minimum filler content of 0.8% of concrete volume was needed in order to attain good conductivity. Also, it was emphasized that the properties of the produced concrete are significantly influenced by the inclusion of conductive fillers and the effect on the concrete properties mainly depends on the type and content of the filler used.

Several investigations found that the electrical resistivity of concrete was greatly affected by its constituent's mainly type and content of aggregate, w/c ratio and sand to cement ratio .The main conclusion was the significant effect of aggregate content on concrete conductivity especially the sand content volume fraction. A sand content volume of 24% or less is needed to attain high conductivity. Also, it was concluded that the concrete air voids adversely affected its conductivity. The effect of filler type, size, content and distribution on the conductivity of concrete was also studied. It was concluded that conductivity of concrete was affected not only by the type and content of fillers but also depends on the dispersion uniformity. The dispersion of fillers was found to be affected by mix proportions, filler content, mixing and efficiency of mixing. Concrete conductivity received considerable attention [1]. Conductive concrete was investigated using different types of conductive fillers or phases in the form of particles or fibers which were included into the cement matrix. Examples of the conductive fillers or phases used are graphite and carbon fibers and microfibers [2–4] steel fibers and micro fibers [5, 6], steel shavings [7, 8], graphite powder [9, 10], steel wool [5, 9], carbon black powder and carbon black nanoparticles [11–14] and carbon nanofibers and nanotubes [15–17].

Investigations have found correlations between concrete resistivity and both the corrosion initiation and the propagation period. The corrosion rate often has an inverse correlation to the electrical resistivity of concrete. Hornbostel *et al.* [18] have compiled a comprehensive literature review on the relation of corrosion rate and electrical resistivity as well as the contributing factors. In general, higher electrical resistivity of concrete lowers the risk and the rate of corrosion. The presence of cracks in the microstructure of concrete can change the transport properties of concrete. Cracks change the connectivity of pore structure, therefore the electrical properties of concrete. The electrical resistivity technique can also be used to detect and monitor the initiation and propagation of cracks in concrete. The development of microcracks in cementitious composite materials under tensile test was accurately determined by Ranade *et al.* [19]. The concept of electrical resistivity has been used to develop test methods for determining the setting time of cement mortars and concrete. As the fresh concrete sets and hardens, depercolation (discontinuity) of the capillary pore space increases the electrical resistivity. Bentz *et al.* [20] studied the feasibility of using electrical resistivity technique for predicting the setting time of cement paste and concrete mixtures. Another potential application of the electrical resistivity method is to determine the moisture content of concrete. Rajabpour *et al.* [21] investigated the use of resistivity measurement in assessing the moisture content of concrete. However, the application and reliability of the method to determine the moisture content has yet to be evaluated.

V Conclusion

Electrical resistivity measurement shows promise as a quality control and performance assessment tool for concrete materials. A relationship between electrical resistivity and diffusion coefficient would be more appropriate for quantifying the criteria required for the durability-based quality control of concrete, particularly those required for the classification of chloride permeability of concrete.

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