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ELECTRICAL CONDUCTIVITY OF CONCRETE

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ABSTRACT

Electrical conductivity of concrete is of current interest since it can be used as a parameter relating to certain characteristics of concrete. Electrical resistivity is the inverse of electrical conductivity. This literary study indicates that moist concrete behave as a semiconductor with resistivity of the order of 10^5 ohm-mm while oven-dried concrete behaves as an insulator with resistivity of the order of 10^{12}ohm-mm.The methods of measuring resistivity are studied which draws to the fact that Wenner probe method being the more reliable method. The principle behind the measuring techniques is to quantify the conductive properties of the microstructure or pore network of concrete. This study also presents the factors affecting the resistivity measurements and applications of the measured conductance in determining certain parameters of concrete.

Keywords: conductivity, semiconductor, parameters.

INTRODUCTION

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 10^5 ohm-mm. Whereas dry concrete has resistivity in the range of 10^{12} 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.

Electrical conductivity measurement

Concrete is a heterogeneous mixture with an interconnected pore network. Depending on the degree of the saturation of the pores (that is, the moisture content), concrete will exhibit conductive characteristics. A concrete sample might exhibit low electrical resistance when it is wet, but the same concrete would have much higher resistance in a dry condition.

The measurement of electrical conductivity appears to be novice, yet the various physical and chemical characteristics of concrete makes it complex to find a technique accurate. Generally electrical conductivity cannot be measured directly. Electrical conductivity is found from the inverse of resistivity. Electrical resistivity is found from the resistance offered by concrete when subjected to electricity.

However, concrete has capacitive properties, which means it can withhold electrical charge. Since direct current (DC) can induce high polarization effects, DC-based techniques are not suitable for measuring electrical resistivity. Alternating current (AC) must therefore be employed to measure the electrical resistivity of concrete. When current is passed through concrete, the ions in the pore solution align in an orderly way, that they can direct the current. This introduces a non resistive opposition to current in the circuit, to the measurements.

Generally, electricity is passed through the concrete by metal electrodes. The electrodes when connected to a suitable circuit, quantify the resistance of concrete. Only the resistance offered normal to the concrete *R,* can represent the ion movement in the porous network. Therefore, a suitable measurement method

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should be adopted to minimize the capacitive response of concrete and accurately measure the resistance. Many configurations have been proposed to measure electrical resistivity of concrete. Depending on the proposed models, various measurement methodologies have been developed. The two-point uni-axial and four-point (Wenner probe) techniques are widely accepted methods.

Two point uniaxial method

In this method, the concrete specimen is placed between two parallel metal plates. A wet sponge is placed at the interface of the electrode and the specimen to ensure proper electrical connection. When electricity is passed, the potential difference between the two electrodes is measured. Electrical resistance *R* is found using:

$$R = V / I$$

Where V is the potential difference developed between the two electrodes and I is the alternating current applied. The geometrical constant *k* used in this method is :

$$k = A / L$$

Where *A* is the c/s area perpendicular to the alternating current; *L* is the height of the prismatic or cylindrical concrete specimen. The resistivity ρ can then be determined from:

$$\rho = R \times k$$

The two point uniaxial technique is a non destructive, yet reliable method for measuring electrical resistivity in laboratory conditions. Hence cylindrical concrete samples casted for the compressive strength test can itself be used for resistivity measurement. However, the utilization of this test method for site evaluation is limited, as this method requires that concrete core samples are taken from the existing structure.

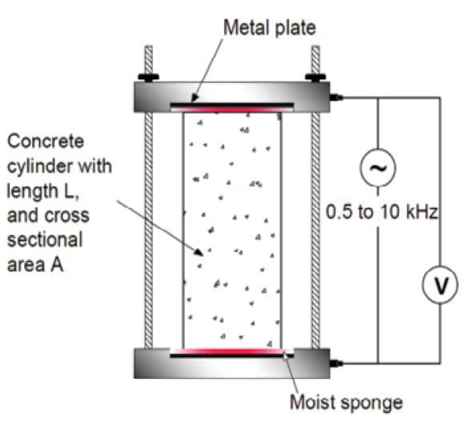

Figure-1. Two point uniaxial method [1].

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. 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. The geometrical factor for a semi-infinite homogenous material, is defined by,

$$k = a \gamma$$

Where *a* is the distance between the equally spaced electrodes; γ is the dimensionless geometrical correction factor. American Standard specify an electrode spacing of 38 mm with a frequency of 13 Hz. The measurements recorded using this method is sensitive to surface condition of the test specimen. Any presence of cracks or reinforcing steel will reflect over the measurements. Hence AASHTOTP 95 specifies to take eight trials over the specimen to obtain a reliable value. The Wenner probe method is most suited for on-site measurement of resistivity due to its configuration.

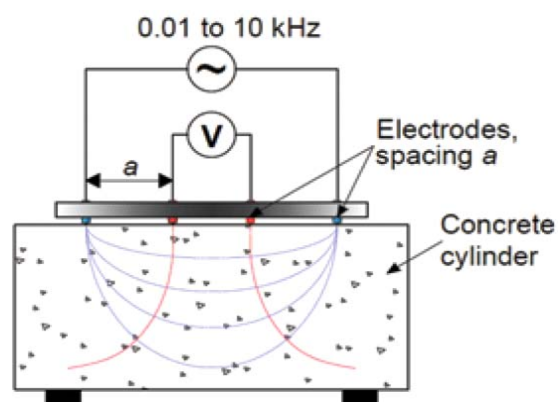

Figure-2. Four point or wenner probe method[1].

One external electrode method

In this method electrical resistance is measured between an external electrode and the reinforcement cage. The external electrode is a circular disc which is placed over the concrete's surface. The caged reinforcements act as a single electrode. The cell constant for this method depends on the cover provided for the reinforcement and diameter of rebar. Since the cover varies over the surface, accurate measurements are not possible. Hence empirical calculations are made to find the cell constant. Polder specifies cell constant of 0.1m for disc, bar diameter and cover depth of 1to 5cm. this method requires continuity between the reinforcements for precise measurements.

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Factors affecting electrical resistivity measurements

The electrical resistivity of concrete is significantly affected by the porous network and interconnection, conductance of pore fluid, temperature and degree of saturation. The contact electrode properties and the alternating current's signal frequency also affects the resistivity measurements. If the effects of these influencing factors are appropriately taken into consideration, any resistivity measurement technique should reciprocate the same resistivity value. A small change in the saturation level will affect the conductivity (or resistivity) of concrete as it leads to variation in the amount of fluid in porous network. It is better to use a consistent curing technique to ensure that the test specimens are in a saturated surface dry condition at the time of testing. This is to make reliable and repeatable electrical resistivity measurements for quality control.

The current flow in concrete is due to the ionic movement within the porous network. The mobility of ions is affected by temperature. In general, an increase in the temperature decreases the electrical conductivity. It has been reported that a temperature change of 1°C can account for 3% change in electrical resistivity of concrete. Therefore, it is necessary to monitor temperature while testing concrete specimens for electrical resistivity measurements.

The general exhibit of the impedance spectrum includes two arcs in high and low frequency modes. But, there is no general specification on the optimum frequency, since it varies with mix proportion and moisture condition. The effect of electrode-contact is of less importance in the Wenner probe method than in the uni-axial method. Hence measurements can be conducted in a wider frequency spectrum of 10 Hz to 10 kHz.

Statistical study

Jaiswal*et al*. [7] have studied the primary factors which influence the conductivity measurements, which points out that the quantity of cement used influences conductivity measurements. The study also indicates that size of the aggregates have an impact on conductivity measurements during lower water to cement ratios. It has been attributed to transition zone where mobility of ions occur. For smaller coarse aggregate proportion and higher water cement ratio, the results were higher electrical conductivity. For high coarse aggregate proportion, there is a difference in conductivity measurements. The study indicates this effect as a result of bleeding or segregation in the mix. The grading of concrete has also been found to have an effect on the measurements.

Alternate to RCPT

Electrical resistivity measurements can be used as a scale of concrete's resistance to chloride penetration. Similar to the Rapid Chloride Penetration test, electrical resistivity measurement can also be used in the evaluation of mobility of ions within the porous network of concrete. The RCPT was initially developed to measure the chloride permeability based on an electric charge Q passing through the concrete over a definite time period t. Whiting proposed different categories for the chloride penetration of concrete specimens based on the electric charge passing through concrete.

Electrical conductance of concrete is due to the transfer of charge by the movement of ions within the concrete's pore network. The presences of ions are attributed to the chemical composition of the constituents of concrete, but the movement of these ions are carried out by the pore solution. The pore solution is diffused with chloride ions over the years. Hence an inverse relation exists between the resistivity and the chloride content in concrete. That is, electrical conductance of concrete increases with increase in the amount of chloride penetration.

Electrical conductivity and corrosion monitoring

Feliu*et al*. have found a linear relation between electrical conductivity and reinforcement corrosion in concrete. The theoretical explanation is the fact that with corrosion is a 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.
Hornbostel*et al.* [11] have studied the relation between corrosion rate and electrical resistivity as well as the contributing factors. He identifies cement in particular to influence the corrosion and electrical conductivity relation. The paper classifies corrosion by its initiator, chlorides and carbonation. The electrical resistivity has found to increase with decrease in corrosion rate. The measurement methods seems to have an impact on the resistivity measurements. The cause of corrosion has also been identified to effect the resistivity measurement.

Electrical resistivity measurements and applications

Theoretical and experimental works relate electrical conductivity with certain characteristics of concrete such as water absorption, chloride diffusion coefficient, and rate of corrosion in embedded steel. Electrical conductivity measurements can also be used as a quality control scale for fresh and hardened concrete.

Crack detection

When the interconnectivity of the pore network in concrete is broken, movement of ions are disrupted. Presences of cracks in concrete act as walls between the movements of these ions, hence the electrical conductance of concrete. Therefore electrical conductivity can be used to detect and monitor crack initiation and propagation of cracks in concrete. Ranade*et al*. [12] have monitored development of micro cracks in cementitious materials under tensile loads.

Setting time measurement

Electrical conductivity can be used to determine the setting time of cementitious materials. The concept behind these evaluations is interconnectivity between the pore networks in fresh concrete is enhanced by the presence of water. As the concrete hardens, the evaporable water dries off leading to a drift in the interconnectivity between the pores. Hence electrical conductivity if concrete decreases.

Moisture content

Another application of the electrical conductivity method is to determine the moisture content of concrete. Rajabpour*et al.* [14] have experimented on the use of resistivity measurement in calculating the moisture content of concrete. The reliability of this method is yet to be determined.

CONCLUSION

Electrical conductivity method proves to be a effective and reliable method for assessing various characteristics of concrete. Moreover being a non destructive test, samples casted for compressive strength test can itself be used for this test. Hence this test is more economical. Among the methods of conductivity measurements the Wenner probe method is the most reliable method and can also be used for on-site evaluation. Among the factors influencing the measurements, consistent monitoring is more primitively needed for temperature control. And also the frequency of the input current and the salinity of water used for mixing concrete influence measurements up to a certain extent. Provided the proper geometric factors or the cell constants the results are near to accurate in developing a relation between certain parameters of concrete. The study shows that conductivity measurements being similar to the rapid chloride penetration test. This test can become an alternate to the existing RCPT.

REFERENCES

Layssi, Hamed, *et al.*Electrical Resistivity of Concrete.Concrete International 37(5): 2015.

Whiting, D. Rapid Determination of the Chloride Permeability of Concrete. Report No. FHWA/RD-81/119, Federal Highway Administration, Washington, DC, 1981, p. 174.

Polder, Rob B. Test methods for onsite measurement of resistivity of concrete-a RILEM TC-154 technical recommendation. Construction and building materials. 15(2): 2001: 125-131.

Claisse, P.A. 2014. Letter: Using Electrical Tests as Durability Indicators. Concrete International, V. 36, No. 10, October, p.17.

AASHTOTP 95. 2014. Standard Test Method for Surface Resistivity of Concrete's Ability to Resist Chloride Ion Penetration.American Association of State Highway and Transportation Officials, Washington, DC.p. 10.

ASTM C1760-12. 2012. Standard Test Method for Bulk Electrical Conductivity of Hardened Concrete. ASTM International, West Conshohocken, PA, p. 5.

Jaiswal, Sanjay S., *et al.* 2000. Statistical studies of the conductivity of concrete using ASTM C1202-94.Concrete Science and Engineering. 2(6): 97-105.

Shri, S. Deepa, and R. Thenmozhi. 2012. An Experimental investigation on the flexural behavior of sccferrocement slabs incorporating fibers. International Journal of Engineering Science and Technology. 4(5).

Morris, W.; Moreno, E.I.; and Sagüés,A.A. 1996.Practical Evaluation of Resistivity of Concrete in 433 Test Cylinders Using a Wenner Array Probe.Cement and Concrete Research. Vol. 26, No. 12, pp. 1779-1787.

Shri, S. Deepa, and R. Thenmozhi. 2012. Flexural behavior of hybrid ferrocement slabs with microconcrete and fibers.Int. JEmerg. Trends Eng. Dev. 4(2): 165-177.

Feliu S, González JA, FeliuSJ, Andrade C. 1989. Relationship between conductivity of concrete and corrosion of reinforcing bars. Br Corros J. 24(3):195-198.

Elkey, W., and Sellevold, E.J. 1995.Electrical Resistivity of Concrete, Norwegian Road Research Laboratory, Oslo, Norway. p. 33.

Hornbostel, K.; Larsen, C.K.; and Geiker, M.R. 2013.Relationship between Concrete Resistivity and Corrosion Rate-A Literature Review. Cement and Concrete Composites. Vol. 39, May 3, pp. 60-72.

Ranade, R.; Zhang, J.; Lynch, J.P.; and Li, V.C. 2014.Influence of Micro Cracking on the Composite Resistivity of Engineered Cementitious Composites," Cement and Concrete Research. Vol. 58, pp. 1-12.

Bentz, D.P.; Snyder, K.A.; and Ahmed, A.M. 2014.Anticipating the Setting Time of High-Volume Fly Ash Concretes Using Electrical Measurements: Feasibility Studies Using Pastes. Journal of Materials in Civil Engineering, July. p. 6.

Rajabipour, F.; Weiss, J.; and Abraham, D.M. 2004.In-situ Electrical Conductivity Measurements to Assess Moisture and Ionic Transport in Concrete. International RILEM Symposium on Concrete Science and Engineering: A Tribute to ArnonBentur, K. Kovler, J. Marchand, S. Mindess, and J. Weiss, (Eds.), RILEM Publications SARL. p. 260.