Electrochemical Impedance Spectroscopy

Concrete is one of the world's main construction materials with worldwide consumption in excess of one billion tons. Quality control of concrete at all stages of construction is an absolute necessity to ensure the requirements of function and durability. Current quality control methods for concrete are based on monitoring the quality and amount of the component materials before mixing, measuring the workability of the fresh mix using relatively crude methods, and then testing the strength of small prepared specimens after a period (commonly 28 days) of controlled storage. Traditional (empirical) workability tests, such as the slump test, or compaction factor tests, do not analyze the concrete per se. To satisfy the need of modern concrete practices (e.g. fast-track construction), sophisticated techniques must be developed for the direct analysis of fresh, as well as, cured concrete.

Background

Concrete is a widely used construction material. As with all construction materials, quality is critical to the performance of the finished structure. Current field quality control techniques for concrete (such as the slump test) monitor bulk physical properties but do not directly measure the individual physical or chemical components of the concrete that are critical to the performance of the material. Currently, methods for measuring performance of concrete are generally implemented after the material has been poured and allowed to set and corrections are difficult or impossible to implement. A technique that could quantify the quality of cements in the field prior to pouring could save substantial time and money.

Electrochemical impedance spectroscopy (EIS), a relatively new and powerful method of characterizing electrochemical properties of materials and their interfaces, is now the method of choice for characterizing interfaces in which the physical and chemical behavior is dependent on several different processes occurring at different rates. In theory, any intrinsic property that influences the conductivity of a metal/solution interface can be examined by impedance measurements. Recently, EIS has been used to monitor the microstructural evolution and pore structure development in cements during the early stages of hydration. The intent of these studies was to develop a quality control technique for concrete at all stages of construction. However, data from these studies have also shown a compositional dependence of cement-aggregatewater systems with respect to their complex impedance. The data indicate that the impedance can be directly related to the aggregate content of a system.

Solution

The same basic approach is used for all of the applications. First the portions and frequencies of the Impedance spectra responsive to the property to be measured are identified. Next, the dependence of those elements on the impedance are quantified. Then a model or relationship is developed to predict the value of the property based on the Impedance spectra.

Impedance methods are based upon the well-established theory of electronic AC circuit analysis with both instrumentation and data analysis techniques being analogous. The fundamental approach of EIS is the application of a

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spectrum of small-amplitude sinusoidal voltage excitations to interrogate the system of interest and the measurement of that systems' response. Samples do not require special preparation prior to testing, and testing can be carried out on large samples, making it easy to examine the bulk properties of the material. The measurement is non-invasive and the instrumentation is relatively simple.

Application

Electrochemical impedance spectroscopy techniques will provide a way to monitor the curing process and long-term performance of cement structures and could also provide a simple, inexpensive method to determine the relative permeability, stability, and durability of cementatious systems. In addition to providing a valuable technique for the construction industry, this work could also facilitate the implementation of jet grouting and other in situ grouting techniques for waste remediation at the INL and other DOE sites.

Benefits

One of the most attractive aspects of EIS as a tool for investigating the properties of materials and their environments is the direct connection that exists between the electrical behavior of a real system and that of an idealized model circuit consisting of discrete electrical components. The impedance of an analogous circuit model (made up of ideal resistors, capacitors, and inductors) can approximate the experimental impedance data.

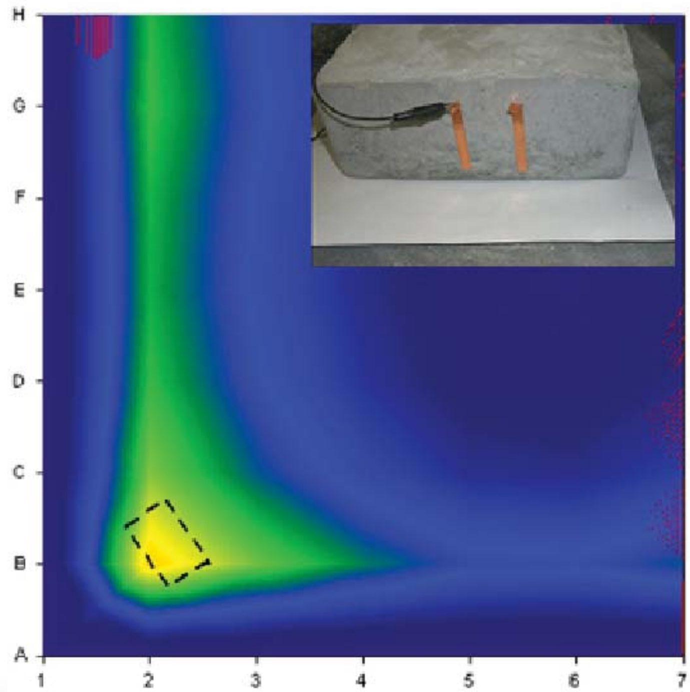

Figure 1. A contour map developed from impedance data collected on a block of concrete containing a void, simulated by the addition of a 2"x2"x1" block of closed cell Styrofoam®. The high impedance area (light) near B-2 pinpoints the location of the void. The insert shows a technique for electroding cured concrete with conducting tape.

In such a circuit, a resistance represents a conductive path and a given resistor in the circuit might account for the bulk conductivity of the material or one step in a chemical reaction at the metal/solution interface. Capacitances and inductances are generally associated with space charge polarization. However, the most important aspect of an idealized model is that changes in the magnitude of the various resistances, inductances, and capacitances, over time reflect changes in specific properties of the materials being measured.

Partnering with INL

The INL's goal is to find a party interested in commercializing this technology. The INL is patenting this technology and invites interested parties to contact us regarding licensing details.

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