

An educational video on the concept and measurement methods of steel corrosion in concrete.

Transcript

Hi! My name is Chris, and today, I am going to talk about different techniques in corrosion study. These methods are based on the electrical response of concrete-reinforcement systems.

In my presentation, I am first going to briefly talk about the corrosion, why it happens, the chemistry or corrosion, and the consequences of the reaction.

Later on, I will talk about how we can detect corrosion.

In the last part, which is going to be the main part of this presentation, test methods in corrosion study are briefly presented and discussed.

So why do steel bars corrode? In simple words, corrosion can be described as a process (chemical reaction) where refined metals such as steel (Iron) return to their more stable combined forms as oxides, carbonates, or sulfides.

In this chemical reaction, a section of the steel material act as Anode. This means that steel loses electrons; On the other hand, another portion of reinforcing mesh acts as cathode. In the cathode, oxygen combines with water and the electrons to release hydroxide ions. This shows that the reactions require both water and oxygen to occur.

We know that the availability of these three elements are essential for corrosion to happen. The reaction requires Water, Oxygen. However, experiments, and real case scenarios show that chloride plays a key role in the onset of corrosion reactions.

When it comes to reinforced concrete elements, it is good to know that the concrete cover protects the reinforcing bars from corrosion. This is due to high alkalinity of concrete material. The higher the resistance of concrete to ingress of ions, the lower will be the chance of corrosion.

The interesting question that raises here is the role of chloride ion in this reactions. This has been the topic of research for many corrosion specialists around the world; yet there is no definite answer to it; a very basic explanation is that the ingress of chloride destroys the protective oxide layer (passive film) on the surface of rebar. This eventually destabilized the

protective film over the reinforcement, which eventually leads to the initiation of corrosion.

Concrete provides a high alkalinity environment around reinforcement. In normal condition, one can expect this will protect the reinforcing bars from corrosion. At the same time, we know that concrete is a permeable material. Moisture and aggressive ions can move through the pore structure of concrete. This is the very mechanism that electrons move inside concrete.

As I mentioned earlier in this presentation, the porosity of concrete makes it possible for ions, to penetrate into concrete, and make it act as an electrolyte. Corrosion reactions happen in this environment. The movement of electrons in concrete creates an electrical potential field inside concrete over the surface of rebar. For example, the reactions in the Anode where steel loses electrons can create a potential difference of -780 mV compared to a standard copper/copper sulfate electrode. The cathodic reactions would be $+160$ mV.

This potential field give us a basis for studying the corrosion of reinforcement in concrete structures. Most of existing corrosion rate measurement techniques are based on studying the electrochemical condition of rebar-concrete interface from the surface of concrete. Different techniques have been developed over the years to study different aspect of corrosion reactions.

In this presentation, I will introduce two major concepts we normally deal with when it comes to corrosion study. The first concept is the half-cell potential measurement. In this method, surface potential measurement is used to predict the probability of corrosion. While the test provides useful information about the chance of corrosion for the area under investigation, the results can easily become misleading if the potential effect of influencing parameters are not appropriately taken into account. Another limitation of the test is that it does not provide any information about the kinetics of corrosion reactions.

The second concept is the rate of steel corrosion. The corrosion rate is about the kinetics of corrosion reactions; how fast they are moving. This becomes important in the context of life-cycle assessment, as it helps engineer better predict the remaining service life of a given structure.

So let's talk a little bit on these concepts and test method for the measurements. Half-cell test can be used to predict the corrosion potential from the surface of concrete. Several standard associations have standardized the test procedure including the ASTM, UNI and RILEM.

In the half cell potential method, the potential values at the surface of concrete is measured with respect to a reference point. Concrete surface should be prepared before doing the test, that is to remove paint or other nonconductive layers from the surface. The surface should have a minimum amount of moisture. A sound electrical connection should be established between the reference electrode and reinforcement.

The value is normally presented in contour plots, showing different half-cell potential values. This helps identify the areas with higher chance of corrosion. For example, ASTM C 876 introduces three different ranges for the measurement. Half-cell potential values (measured in reference to copper sulfate electrode) less than -350 mV represent area where probability of having active corrosion is more than 90%.

When measurement is higher than -200 mV, this probability is less than 10%. Results for half-cell potential values between -200 mV to -350 mV in uncertain.

When it comes to half-cell potential values, one should take into account the effect of environmental conditions (such as moisture and humidity), as well as the properties of concrete materials (dense concrete versus porous concrete, carbonated concrete). There are some complications along the way when we are performing a half-cell measurement. High electrical resistivity of concrete cover, decrease in moisture content of concrete as well as increase in the thickness of the cover, make half-cell readings less accurate. Also, a decrease in oxygen concentration at the surface of the steel reinforcement for instance for concrete in fully saturated condition will result in a more negative corrosion potential reading.

When doing a half-cell potential test, one should remember that the surface should be free of paint, and chemical epoxy coatings. Also, the test on stainless steel reinforcement and epoxy coated rebar will increase the chance of error in making the measurements.

The second group of tests that I am going to present today, are those dealing with the measurement of corrosion rate of steel reinforcement in concrete. These tests provide important information on the kinetics of reactions. Most of these techniques are based on measuring the polarization resistance of a corroding rebar. This is normally achieved by exciting the steel-concrete interface by passing a direct current through the system. The corrosion rate is measured through the measurement of polarization resistance, that is the ratio between the applied voltage to the measured current or vice versa, when a small potential or current has applied to the system.

Using Stern-Geary equation, one can measure the corrosion rate. In this equation, the B is the Stern-Geary constant and can be determined numerically by knowing the anodic and

cathodic Tafel coefficients or experimentally by measuring the mass loss; The other important parameter is the polarized area.

A number of test procedures have been developed to calculate the polarization resistance.

I will start with linear polarization resistance (LPR) measurement. In this technique, a three-electrode cell (with or without a guard ring for current confinement) is used. The test relies on the identification of the linear portion of the potential drift vs. current relationship around the open-circuit potential of the experiencing cathodic polarization. There are two approaches to do a LPR test: Potentiostatic sweep, in which voltage is increased with a constant sweep rate, and the response current is recorded; or Galvanostatic sweep, in which the current is increased with a constant sweep rate, and the response potential is recorded. It is generally suggested the sweep should not go beyond ± 12 mV on both sides of the open-circuit potential; otherwise the linearity of the relationship cannot be assured. It is worthy to mention that the polarization resistance measured by this technique (R_t) includes the concrete (electrolyte) resistance (R_c).

The next technique I am going to talk about is the galvanostatic pulse technique. The main concept used here is very similar to the LPR. An anodic current pulse is galvanostatically applied to the rebar from the counter electrode placed on the surface of concrete.

The magnitude of the applied current is normally in the range of 2 to 400 μ A, and the duration of pulse is less than 30 s. This small anodic current changes the potential of rebar in concrete. In fact, the rebar (working electrode) is polarized in the anodic direction starting from the open-circuit potential.

Access to the rebar is essential for the electrical connection of the instruments that use this technique. The potential is measured by a reference electrode located at the center of probe and the current is applied through a counter electrode placed around the reference electrode. A guard ring is usually used in this type of instrument to confine the current distribution along the rebar.

The next technique is the AC impedance method, where an AC current is used to study the electrical response of a corroding bar in concrete. AC impedance technique is a very powerful technique in corrosion study. A small AC potential is applied to the rebar, and the current response is analyzed. Then the impedance of the system is determined. This is done over a wide range of frequencies, which makes it time consuming (especially in the lower end of the frequency spectrum). The response of the system in the higher frequency range is more representative of concrete material, while the lower range is a good indicative for rebar-concrete interface condition. The difference between the two can yield the polarization

resistance.

The method is difficult to be used as a field technique, but can be a very useful technique in laboratory investigation.

Connectionless Technique

The connectionless technique is the most recent technique developed to measure the corrosion rate of corroding rebar in the field. This technique is unique since it does not require any rebar connection, which makes it faster and more efficient.

In this technique, the low-frequency behavior of reinforced concrete system is determined by applying a narrow current pulse or a step voltage/current for a short period of time (in a couple of seconds); At the same time, the voltage drift is recorded using a high sampling rate. The lower frequency impedance of the system is then measured, and used to predict the state of corrosion. [Read more [here](#).]