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Effects of Chloride on Corrosion Damage of Reinforced Concrete Structures

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Abstract: Corrosion is one of the most critical problems that impair the durability of RC structures. Both carbonation-induced and chloride-induced corrosion widely prevail in civil infrastructure around the globe. Expansive products are formed due to corrosion at the interface between concrete and reinforcing bar (rebar). The cracking and spalling in concrete due to expanding corrosion products and the reduction in the cross-sectional area of rebar jeopardize the safety and serviceability of RC structures.

Keywords: Corrosion; Reinforced Concrete; Chloride; Protection

1. Introduction

Corrosion of rebar in concrete is one of the most frequent causes of premature failure of concrete infrastructures. It is one of the major durability problems, mainly when the rebar in the concrete is exposed to the chlorides either contributed from the concrete ingredients or penetrated from the surrounding chloride-bearing environment. Carbonation of concrete or penetration of acidic gases into the concrete, are the other causes of reinforcement corrosion. Besides these there are few more factors, some related to the concrete quality, such as w/c ratio, cement content, impurities in the concrete ingredients, presence of surface cracks, etc. and others related to the external environment, such as moisture, oxygen, humidity, temperature, bacterial attack, stray currents, etc., which affect reinforcement corrosion. The assessment of the causes and extent of corrosion is carried out using various electrochemical techniques.

2.Reinforced Concrete Structures with Corrosion Damage due to Chloride Attack

It is well known that the chloride in concrete can result in rebar corrosion. Due to the expansive nature of rust, rebar corrosion deteriorates the reinforced concrete structures by creating damages in the concrete around the rebar such as cracking ands palling, which affect the durability and service of life of reinforced concrete structures.

Among the factors affecting the durability of concrete structures, reinforcement bar(rebar) corrosion due to chloride attack is one of major factors. In general, the deterioration process of reinforced concrete due to corrosion can be divided into three stages:

Penetrations of chloride ions and moisture into concrete. This stage ends when the corrosion starts at the critical level of chloride accumulation on the surface of rebar.

Rust formation and rust permeation in surrounding concrete. This stage ends when concrete cracking takes place.

Crack propagation due to continuous rust expansion. The end of this stage indicates the failure of the structure, which is manifested as spalling and/ordelamination of concrete cover.

Generates a more corrosive environment in the concrete mixture compared with NaCl. Corrosion potential increases with the increase of chloride concentration, but can be retarded by the presence of other additive, such as silica fume. Inclusion of pulverized fuel ash, ground granulated blast furnace slag, and silica fume increases concrete electrical resistivity. If seawater is used as mixing water, concrete compressive strength, splitting tensile strength, flexural strength, and pullout bond strength are expected to increase at early ages up to 14 days and decrease forages more than 28 days.

Corrosion results in deteriorating rebar area, yield strength, ultimate strength, and ultimate strain. Concrete crack width in-creases with an increase in corrosion level. Mass loss is higher under freeze-thaw cycles and high temperatures. Increase in water-cement ratio, wet and dry cycles, and tensile stresses ac-celerate chloride penetration rate, while compressive stresses have the reverse effect. Use of rebar bundles to replace a larger diameter rebar is not recommended. Bond strength increases with increase in corrosion level up to a critical percentage (approximately 2–4% of mass loss) and then decreases. The bond strength of corroded rebar increases with increasing concrete cover-to-rebar diameter ratio and concrete tensile strength.

3.Effects of Corrosion Pits on Mechanical Properties of Corroded Steel Bars

Corrosion of steel bars in concrete has become the primary cause for the premature deterioration of reinforced concrete structures, which can lead to structural failure including loss of serviceability, reduction of load-carrying capacity, and even partial or full collapse. It has been shown by previous test results that the nominal yield strength and ultimate strength and the ultimate strain of the steel bar decreases, and the yield plateau of the steel bar is shortened or even disappears with the initiation and propagation of corrosion. It is also found that reduction of the nominal ultimate strength due to corrosion is much higher than that of the nominal yield strength. Since the minimum cross section and the corresponding maximum cross-sectional loss ratio of corroded steel bars is difficult to determine precisely, the nominal yield or ultimate strength of corroded steelbars is usually judged by the average cross sectional area while the corroded steel bars under tension are usually broken at the weakest section with the smallest cross sectional area. In addition, stress concentration usually takes place at the sections with corrosion pits and causes further degradation of mechanical properties. As a result, degradation of mechanical properties of corroded steel bars can be attributed to a combination of variation of cross-sectional area and stress concentration of corrosion pits. In order to investigate degradation mechanism of mechanical properties of corroded steel bars, stress concentration caused by corrosion pits and its effects on mechanical properties are normally analyzed by numerical simulation, in which corrosion pits are simply simulated by inverse trapezia, U shape or V shape. Since stress concentration depends on the shape of corrosion pits, it is therefore important to identify its geometric shape.

The following conclusions are derived based on the numerical simulation results of steelbars with corrosion pits:

Reduction of the nominal strength of corroded steel bars is mainly caused by acombination of the variation of the cross-sectional area along the longitudinal axis and the multi-axial stress at the corrosion pits due to the stress concentration

Degradation of the ultimate elongation and shortening of the yield plateau results mostly from the stress concentration at the corrosion pits.

4.Measures Taken to Prevent the Corrosion of Reinforced Concrete Structures

To prevent such corrosion problems at new concrete structures exposed to deicing salts or other aggressive environments, the design codes for reinforced concrete structures in many countries have been improved. Depending on the environmental conditions more restrictive minimum cover thicknesses and maximum values for the water/cement-ratio have been defined to ensure asufficiently high quality of the concrete cover resulting in a high resistance of the structures against corrosion due to chlorides or carbonation. But often cases remain, especially under extremely aggressive environments, in which additional protection measures are necessary to ensure a sufficiently long service life. In such cases a corrosion protection strategy has to be developed to prevent damages induced by corrosion of the reinforcement, e.g. to use stainless steel or epoxicoated reinforcement or to apply a coating onto the concrete surface and to observe the condition of the structure in regular intervals. Besides a lot of different possibilities one corrosion protection strategy is to ensure a high thickness and quality of the concrete cover and to monitor the corrosion risk for the reinforcement permanently by installing a suitable warning system. If the warning system shows no actual corrosion risk over the whole service life of the structure, no additional protection measures are required. On the other hand, if the monitoring system indicates a high corrosion risk for the reinforcement after a certain period of use, protection measures can be carried out before corrosion starts and any cracks and spalls occur on the concrete surface. Normally the expenditure for such protection measures, e. g. coating of the concrete surface or installation of acathodic protection system is low compared to the costs for the repair of the structure after cracks and spalls have occurred.

4.1. Galvanic Corrosion for Protecting Reinforced Concrete Structures Against Corrosion

Continued research and development into the use of galvanic corrosion protection for protecting reinforced concrete structures against corrosion is providing new alternatives for owners. Cathodic protection can halt corrosion in concrete structures, even under severe conditions. Corrosion Control may be more applicable where the desire is to extend the service life of the existing structure and it is not cost effective or practical to catholically protect the entire element or structure. Corrosion Prevention may be the most cost effective option where the intent is to prevent corrosion from initiating in locations where a sufficient level of chlorides ispresent. Galvanic corrosion protection systems can be designed using the range of galvanic anodes which are available to provide safe, low maintenance Corrosion Prevention, Corrosion Control, or Cathodic Protection for prestressed and post-tensioned concrete structures. The preferred system will depend on the level of corrosion protection required by the owner, as well as the cost and practicality of installation.

4.2. Chloride Extraction Protecting Reinforced Concrete Structures Against Corrosion

Chloride extraction and realkalization are nondestructive, electrochemical treatments to halt and prevent corrosion in chloride-contaminated and carbonated concrete, respectively. The process actually removes chloride ions from the contaminated concrete by the principle of ion migration while at the same time raising the pH of the carbonated concrete through electro-osmosis. Concrete to be treated is first tested to determine the level of chloride contamination. Then, after preparing the surface, a steel or titanium mesh electrode is attached to the structure. The electrode is embedded in a nontoxic biodegradable electrolytic media. Next, electric contacts are established between the attached electrode and the steel reinforcement bars (rebars) inside the concrete. When an electric field is applied, chloride ions migrate away from the rebars and towards the externally attached electrode, eventually ending up in the temporary electrolytic media, which is then discarded. Simultaneously, alkali ions migrate from the electrolyte into the concrete, raising its pH to the original levels. The passivating layer of the rebars is thus reestablished to protect them from corrosion.

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