Monitoring of the Corrosion of Reinforcing Steel Bar in RC Slab by Electrochemical Method

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Abstract

Corrosion of steel reinforcement initiated by chloride contamination has become a common type of deterioration for RC slab used for road bridges in snowy cold regions. Chlorides are present in the RC slabs from the exposure to de-icing road salts. The chloride ion diffuses into RC slab to contact the reinforcements and initiate the corrosion process. So, monitoring of reinforcement conditions in RC slab by non-destructive techniques for the detection of corrosion initiation of reinforcement is a key factor for the maintenance of RC slab. Half-cell potential measurement is a simple, inexpensive and virtually nondestructive technique for assessing the corrosion risk for reinforcements embedded in concrete. The measurements can be used to estimate the corrosion risk even if there are no signs of corrosion on the concrete surface, which is a significant advantage for inspecting RC bridge structures.

This study principally aimed to assess the corrosion development of reinforcing steel within RC slab subjected to a sodium chloride solution of 10% in the concentration, through continuous half-cell potential monitoring system using Pb/PbO₂ reference electrode. In addition, a portable corrosion meter was also employed at a periodic interval to obtain the polarization resistance as well as half-cell potential using Ag/AgCl reference electrode. To make compatible with real RC slab a two-layer of reinforcing steel was arranged in the specimen in this study. It was expected that the first layered rebar near the concrete surface (UP) that was exposed to the salt solution would be corroded followed by the corrosion of the second layered rebar (Down).

Recently fly ash concrete has been practically employed to RC slab in snowy cold region so that the durability of the RC slab can be enhanced. However, the effect of fly ash addition in the concrete on the corrosion development of the two-layer rebar in RC slab is not clarified yet. Then specimen made from fly ash concrete were studied and compared with normal concrete in relation to the corrosion development in this research.

Pozzolans are materials which when mixed with cement and water form C-S-H whereas latent hydraulic materials require a catalyst to produce C-S-H. The addition of these products to a concrete mix reduces the cement requirement for strength and enhances its durability over time. The most prevalent additions are ground granulated blast furnace slag, fly ash, and silica fume. Ground granulated blast furnace slag and fly ash are waste products of steel production and coal-burning power stations, respectively, and incorporating them into concrete mixes reduces energy consumption by reducing the cement requirement of the mix as well as recycling waste. The presence of fly ash reduces the heat of hydration as well as the mixing water required for a particular slump. The reduction of the water requirement is extremely important for achieving low w/c mixes (i.e., high performance concretes). The presence of carbon in the fly ash can interfere with air-entraining admixtures and detrain air. In addition, carbon retards setting and strength development at very early ages (i.e., up to 21 days). After approximately 28 days, however, concrete mixes that contain fly ash can have strengths that are equivalent or exceed non-fly ash concrete mixes. This is a result of the fly ash reacting with the CH that may accumulate at interfaces and depositing C-S-H thus improving the interface bond and the bulk strength of the overall concrete.

Corrosion of two layer of reinforced concrete structure

Iron and plain carbon steels (iron alloyed with small amounts of carbon) are thermodynamically unstable materials. The corrosion of steel reinforcing bars is an electrochemical process that requires a flow of electric current and several chemical reactions. In a corrosion cell, there are two half-cell reactions (Hammer A T, 2008). One of the half-cell reactions, called the anodic reaction, is the dissolution of iron, i.e. an oxidation of iron to form ferrous ions and leaving behind electrons in the metal. In the other half-cell reaction, called the cathodic reaction, the liberated electrons from the oxidation of iron are consumed by oxygen in the presence of water to form hydroxyl (OH⁻). The electrolyte is the medium that facilitates the flow of electrons between the anode and cathode. The anode and cathode can be located next to each other or can be separated. When they are located immediately next to each other, i.e., on a microscopic scale, the resulting corrosion cell is referred to as a microcell. When they are separated by some finite distance, the resulting corrosion cell is referred to as a macrocell (e.g., in two layer of reinforcement) (Smith J L et.al., 2000). The initiation and continuation of the corrosion process are controlled by the environment in the concrete surrounding the steel reinforcing bars. However, corrosion occurs more rapidly under conditions of exposure to chlorides. Using de-icing salt in concrete bridge slab is a common phenomenon for reinforcement corrosion due to chloride attack. A typical corrosion cell in two layers of reinforcement with chloride ingestion has shown in Figure 1. Corrosion is assumed to start when the concentration of chlorides at the embedded steel surface has reached a certain so-called ‘chloride threshold’ value or critical chloride content. The chloride typically enters the concrete from the top surface. Once the chloride threshold has been exceeded in up rebar, the local disruption of the passive film initiates corrosion cells between the active
corrosion zones (anode) and shift the potential of the up rebar to a negative value while potential of the down rebar that are still passive (cathode) set up a corrosion cell called mac rocell (Smith J L et.al, 2000) as shown in Figure 1. Chlorides actually act as a catalyst in this process to facilitate the initiation of corrosion.

Figure 1. A schematic illustration of a steel corrosion cell in RC slab (Yang Z. et.al, 2013)

The limits on chloride content of constituents have recently been questioned in view of the increasing use of supplementary cementing materials. It is found that with the addition of fly ash average corrosion initiation of fly ash concrete is about 6 times earlier than that of normal concrete. Based on corrosion initiation Chloride Threshold Level (CTL) was examined and significant drop of chloride threshold level in fly ash concrete was confirmed. In addition, reduction in corrosion area measured on the corroded rebar s in between fly ash concrete and normal concrete was also observed. Based on actual corrosion area, actual corrosion current density was estimated. It was found that actual corrosion current density was higher than the corrosion current density measured from the non-destructive way of the electrochemical method. Through the examination of the alkalinity in concrete at the vicinity of rebar s by Thermo-Gravimetry/Differential Thermal Analyzer (TG/DTA) analysis the CH (Portlandite) content was found less in fly ash concrete compared to normal concrete. Although pozzolanic reaction improves the denseness and discontinuity in pore network, it also reduces the alkali content in the concrete. Reduction in hydroxyl content at the vicinity of rebar s leads to initiate corrosion at a lower chloride level. To yield maximum benefit from using fly ash in RC slab it is now burning issue to set a threshold level for the fly ash concrete considering mixture proportions of concrete. This study also focused on the characterization of corrosion products in the reinforcement in normal and fly ash concrete. Raman spectroscopy was used to characterize the corrosion products developed on the surface of reinforcing steel embedded in RC slab. Two regions of different colours (Yellow, Grey) on the surface (Figure 2) were identified as different corrosion products among oxides and oxyhydroxides compounds like hematite (α-Fe₂O₃), magnetite (Fe₃O₄), wüstite (FeO), maghemite (γ-Fe₂O₃), goethite (α-FeOOH) and lepidocrocite (γ-FeOOH).

Corroded Area (Light region: Yellow color; Dark region: grey color)

Figure 2. Reinforcement used for Raman test

Since the corrosion products characterization by Raman microscopy was performed in a small area (laser spot 4μm²), a quantitative contribution of each phase found is not possible even probing different regions. However, it was possible to associate the colour of the oxide to a particular phase. Raman results presented in this study, different iron compounds were observed on the reinforcement extracted from normal and fly ash reinforced concrete. Regarding the influence of fly ash in concrete it was noticed that the main corrosion products generated on the surface of steel embedded in fly ash concrete in the presence of chlorides were poorly crystallised phases of iron oxyhydroxides, goethite (α-FeOOH), lepidocrocite (γ-FeOOH) and hematite (α-Fe₂O₃) while in normal concrete the main corrosion products in rebar surface was found strong goethite (α-FeOOH) compound with iron oxyhydroxides, lepidocrocite (γ-FeOOH), hematite (α-Fe₂O₃) and wüstite (FeO). However, small peaks of magnetite compound were also found in normal concrete. Moreover, the dark region is more stable phase than the light region. In the initial stage of corrosion, the corrosion products are mainly several iron oxyhydroxides with low intensity, however, these corrosion products are transformed to several strong products such as akaganite compound depending on the aggressive chemical substance (chlorides, sulphates) (Marcotte, 2001). However, neither Fe₂O₄ nor akaganite were detected in all the fly ash specimen, indicated that the amount of chlorine was not enough in the DPL to stabilize this phase (Criado M, et.al. 2015). Because, to stabilize the dense corrosion product layer (DPL) it is required to present the goethite, lepidocrocite, akaganite product with Iron oxides compound (magnetite, hematite) (Chitty J et.at. 2005).

References