Reinforcement Corrosion Assessment Using PZT Sensors via Electro Mechanical Impedance Technique

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***Abstract*—Reinforced concrete (RC) is an economical, versatile and successful construction material as it can be moulded into a variety of shapes and finishes. In most cases, it is durable and strong, performing well throughout its service life. However, in some cases, it does not perform adequately due to various reasons, one of which is the corrosion of the embedded steel bars used as reinforcement. Although the electro-mechanical impedance (EMI) technique is well established for damage detection and quantification of civil, mechanical and aerospace structures, only limited studies have been reported of its application for rebar corrosion detection in RC structures. This paper presents the recent trends in corrosion assessment based on the model derived from the equivalent structural parameters extracted from the impedance spectrum of concrete-rebar system using the lead zirconate titanate (PZT) sensors via EMI technique.**

Keywords— Corrosion, EMI technique, Piezo sensor, Rebars, concrete, Equivalent parameters, Corrosion rate, Carbonation

1. Introduction

Concrete is easy to use construction material which is widely used next to water. Its lack of adequate tensile strength is taken care by steel reinforcement bars. The corrosion of steel reinforcement embedded in concrete is most frequently due to the breakdown of the passive film formed in the highly alkaline environment of concrete. Two conditions can break down the passive environment without attacking the concrete, one is chloride attack and the other is carbonation attack. The service life of reinforced concrete (RC) structures exposed to these ions consists of two phases, namely the initiation phase and the propagation phase. Rebar corrosion is generally accompanied by the loss of rebar cross section and accumulation of corrosion products, which occupy much larger volume than the original steel, thereby generating tensile stresses, which lead to cracking and spalling of concrete, commonly known as concrete cancer. Hence, timely detection of corrosion and quick remedial action can prolong the service life of the structure.

In the EMI technique, a PZT patch is surface bonded to the monitored structure and electrically excited by means of an impedance analyzer/LCR meter. Under external field excitation, the bonded patch induces deformations in the host structure, whose response is transferred back to the patch in the form of admittance function, consisting of conductance and susceptance. This admittance signature is acquired over a high frequency range (30-400 kHz), forms the bench mark for assessing the structural health. The EMI technique has been experimentally found to be very powerful in detecting localized incipient damage in a variety of structures. This technique is also very effective and sensitive in detecting the damage (loss of structural parameters) caused to the structures. The section presents the application of this technique for corrosion assessment.

2. Chloride Induced Corrosion In Rc Structures

One of the most common causes for rebar corrosion in RC structures is the presence of chloride ions. They cause localized breakdown of the passive film that initially forms around steel as a result of the alkaline nature of the pore solution in concrete. The aggressive chloride ions can originate either from the contaminated mixing ingredients in the fresh state or from the surrounding environment in the hardened state. It has been reported in the past that the corrosion initiation takes place when the chloride concentration at the rebar level reaches a critical level, which is also often referred to as the threshold level. The time for the chloride ion concentration to reach a critical level for the onset of corrosion is known as the 'initiation Period'. Once the protective layer around the reinforcement has been removed, corrosion can take place in the presence of moisture and oxygen. The time taken for corrosion to result in sufficient deterioration such that remedial action is required is known as the 'propagation period'. Different conceptual models are proposed to describe the corrosion process of steel rebar in concrete. The concept of Initiation and Propagation periods can be illustrated by famous Tuutti's model. A schematic representation of Tuutti's model illustrating the initiation and propagation periods is presented in Fig.1.

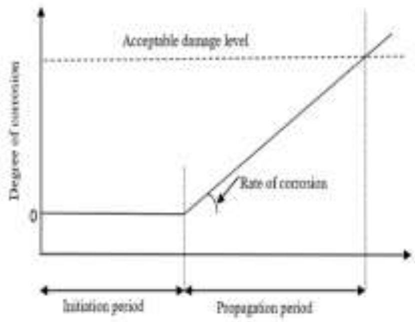

Figure 1 Tutti's model of corrosion initiation and propagation

3. Chloride Induced Corrosion Assessment Using PZT Patch Via EMI Technique

Recently developed non-dimensional parameters based on equivalent structural parameters extracted from impedance spectrum to assess the corrosion. The study involved four RC cubes of M20 strength, 150 x150 x 150 mm in size with high yields deformed (HYD) steel rebars of 200mm long, and bonded with a square PZT patches. Under normal environmental conditions, corrosion of a rebar is a relatively slow process, often taking several years to progress significantly. In order to obtain the results in a reasonable time frame for a laboratory-based study, accelerated corrosion through impressed current technique was adopted. After the baseline signatures were acquired, the specimens were placed in a beaker containing "brine" solution (of salinity 35 parts per thousand). To accelerate corrosion, an electrical loop was set up with the steel bar forming the anode and the negative terminal was connected to a copper bar dipped in the solution acting as cathode, as shown in Fig. 2. A constant current 150μA/cm^2 was applied to the specimens using fixed power supply device. Accelerated corrosion tests were performed for a period of 120 days.

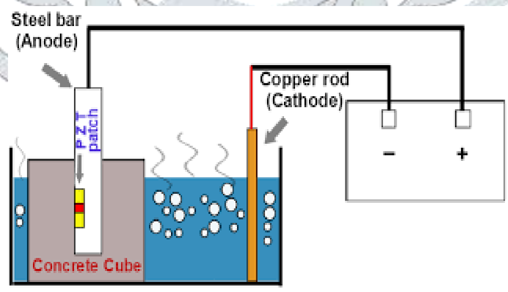

Figure 2 Accelerating corrosion set up

In order to monitor the changes in the RC specimens during accelerated corrosion, the shift in the magnitude and frequency of the conductance signature was tracked at the resonance peak. Figs. 3 shows the acquired conductance signatures of the PZT patch bonded during the accelerated corrosion period of 120 days. As seen from the figure, the peaks of the conductance signature have reduced considerably during the corrosion process. The reduction in the magnitude of the peaks was attributed to increase of the damping at the rebar concrete interface due to the formation of corrosion products and also due to the associated cracking in the concrete.

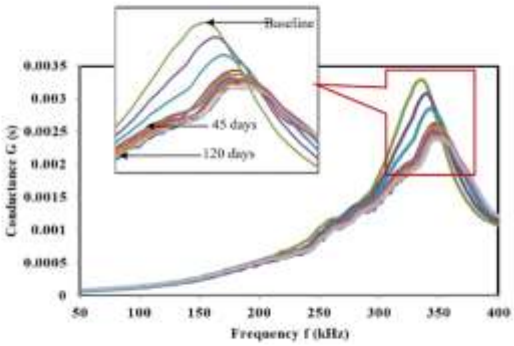

Figure 3 Variation of conductance signatures of specimen 1 during accelerated corrosion process

4. CARBONATION INDUCED CORROSION DIAGNOSIS

The authors had extended the developed chloride assessment model for carbonation corrosion. Besides the chloride induced corrosion, the other commonly occurring type of rebar corrosion in RC structures is that induced by the ingress of atmospheric carbon dioxide into concrete, commonly referred as carbonation induced corrosion. Carbonation is the result of the interaction of carbon dioxide gas in the atmosphere with the alkaline hydroxides in the concrete. Like many other gases, carbon dioxide dissolves in water to form carbonic acid. The carbonic acid does not attack the cement paste, but just neutralizes the alkalies in the pore water, mainly forming calcium carbonate that fills the pores as given by following equation

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Calcium hydroxide is not the only substance that reacts with CO_2, the other hydration products and even the residual unhydrated cement compounds also take part into carbonation reactions.22 The formation of calcium carbonate requires three equally important substances: carbon dioxide (CO_2), calcium phases (Ca), and water (H2O). Carbon dioxide is present in the surrounding air, calcium phases mainly calcium hydroxide ($Ca(OH)_2$) and calcium silicate hydrate (C-S-H) are present in the concrete, and water is present in the pores of the concrete. The process of carbonation is schematically illustrated in Fig. 4.

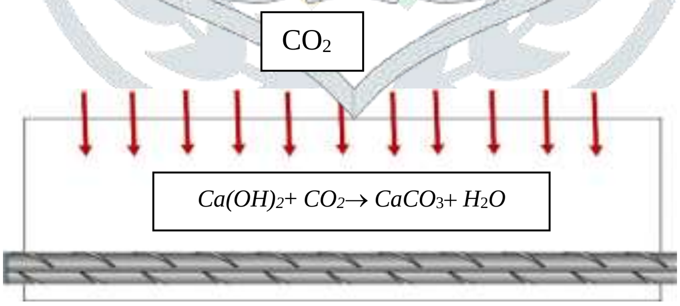

Figure 4 Schematic diagram of CO_2 ingress

5. CONCLUSIONS

The aim of this paper is to present the recent trends of corrosion assessment using EMI technique. The paper presents the application of the equivalent structural parameters for corrosion assessment of rebars in RC structures and related empirical corrosion assessment model derived. The equivalent stiffness coefficient Λ_k can be directly used in an actual scenario, to provide real time information about level of corrosion induced damage non-destructively and can be substitute to the conventional electro-chemical techniques. The various phrases of corrosion have been identified with the developed model value of $\Delta k/k$ over 0.2 indicates initiation of corrosion and over 0.4 indicates alarming corrosion level. The other type of corrosion, namely carbonation induced corrosion has also been studied under an accelerated carbonation environment for a period of 250 days. The equivalent stiffness identified by PZT patch is effective in tracking the changes due to carbonation and found to increase initially, due to filling of pores of cement paste by calcium carbonate thus providing some additional stiffening. Once the corrosion started, the values are found to decrease. From the plots of Δk/k, the corrosion initiation period has been identified non-destructively

6. REFERENCES

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