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BASIC METHODS OF MONITORING OF CORROSION PROCESSES OF CEMENT STRUCTURES AND THEIR IMPLEMENTATION FOR PROJECTING OF POSSIBLE MINERALOGICAL CHANGES IN MATRIX COMPOSITION: REVIEW

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Long time service of concrete constructions is accompanied by continuous impact of environment on its structural integrity and capability to carry project capacity of constructions. This influences are able to change not only chemical composition of cement matrix but itself activates corrosion processes that have place to occur on the joints of metal rebar and cement matrix in reinforced concrete (RC). Chemical initiation in the reinforced concrete begins due to the migration of water with parts of molecular oxygen in the thickness of concrete via porous structure of material. The same can be said about the injected compounds of either SO_4^{2-} *or* Cl^- *components that both can be present either in environment or concrete itself due to the modifications of slurry. Such occurrences usually accompanied by changes of pH of the environment that is crucial for the electrolytic environment to appear. Therefore, the process of the reduction of water/proton may begin at rebar surface wich is the cause not only of the reinforced concrete rebar corrosion but also are reason of accelerated cement matrix degradation. Also, must be noted, that steel corrosion in RC accompanied by changes in current flow. Thus, by understanding the chemical processes and changes that occur in cement matrix of concrete and basics of steel corrosion initiation under the influence of aggressive solutions, the list of non-destructive methods of monitoring (NDM) based on electrical methods of monitoring are reviewed.*

Different approaches using electrical methods of corrosion monitoring has shown that the use of any of the technics either measurements of the corrosion potential or concrete resistivity or polarization resistance provides different results in mapping of areas with high corrosion risks, monitoring of the heterogeneity of concrete and insights on transport phenomena (e.g. water and salts ingress) in the material. Moreover, advances in potential monitoring without connection to the rebar as non-destructive measurements have shown their effectiveness. Nevertheless, colligation of the results of both numerical and NDM methods is necessary for assortment the results to provide a better data of the worktime of RC structures.

Key words: *concrete, corrosion, electrical monitoring, non-destructive methods, aggressive environments, steel rebar.*

Коваленко Ю. О. Основні методи моніторингу корозійних процесів цементних конструкцій та їх впровадження для проектування можливих мінералогічних змін складу матриці: огляд

Довготривала служба бетонних конструкцій супроводжується безперервним впливом навколишнього середовища на їх структурну цілісність і здатність підтримувати запроектовані несучі властивості. Ці впливи, здатні змінювати не тільки хімічний склад цементної матриці, але й самі активують корозійні процеси, котрі відбуваються на з'єднаннях металевої арматури і цементної матриці в залізобетоні (ЗБ). Хімічне ініціювання в залізобетоні починається за рахунок міграції води з частинами молекулярного кисню в товщі бетону через пористу структуру матеріалу. Те саме можна сказати про введені сполуки SO_4^{2-} *або* Cl^- *вмісних компонентів, котрі також можуть бути присутніми як в навколишньому середовищі, так і в самому бетоні у зв'язку з модифікуванням розчинів. Такі явища зазвичай супроводжуються змінами pH середовища, що є вирішальним для появи електролітичного середовища. Таким чином, процес відновлення води/протону може початися на поверхні арматури, що є причиною не тільки корозії залізобетонної арматури, але й є причиною прискореної деградації цементної матриці. Також слід зазначити, що корозія сталі в ЗБ супроводжується зміною струму. Таким чином, з огляду на* *розуміння хімічних процесів і змін, які відбуваються в цементній матриці бетону та основ ініціації корозії сталі під впливом агресивних розчинів, розглянуто перелік неруйнівних методів моніторингу (НММ), заснованих на електричних методах моніторингу.*

Різні підходи з використанням електричних методів моніторингу корозії показали, що використання будь-якої техніки, будь то вимірювання корозійного потенціалу або питомого опору бетону чи поляризаційного опору, надає різні результати в картографуванні зон з високим ризиком корозії, моніторингу неоднорідності бетону та уявлення про транспортні явища (наприклад, потрапляння води та солей) у матеріал. Крім того, прогрес у моніторингу потенціалу без під'єднання до арматури як неруйнівній метод вимірювання показав свою ефективність. Тим не менш, об'єднання результатів як чисельних методів, так і методів НММ необхідне для сортування результатів, щоб забезпечити кращі дані про довговічність роботи ЗБ-структур.

Ключові слова: *бетон, корозія, електричний моніторинг, неруйнівні методи, агресивні середовища, сталева арматура.*

Introduction. Usage of the reinforced concrete (RC) mostly connected for its environmental applications in demand for strategical planning in construction of bridges, dams, powerplants etc [1–4]. Its workable flexibility allows to shape forms of the structural geo-wonders and maintain service orientation of the structures for planned purposes. Nevertheless, with time RC has tendency for degradation under the environmental influence. Mostly, main reasons of RC degradations occur under the influence of aggressive agents such as SO_4^{2-}, CO_2, Cl^-, that infiltrate through the thickness of the concrete up to the rebar [5–9]. This leads to structural changes that crucially affects not only rebar but also lead to chemical changes in mineral compositions of cement binder of concrete wich are devastating for construction capacity [9]. Several technics have been developed for understanding the mechanisms of degradation of RC, among them, electro-chemical [10]. This short review introduces the general knowledge to the mechanisms of cement corrosion (degradation) by influence of the aggressive environments and also processes that occur during RC corrosion and then emphasise on the advantages and drawbacks of the electrochemical monitoring.

1. Corrosion mechanisms in reinforced concrete

Most of the corrosion processes of the RC occur due to chemical-physical processes that take places during infusion of aggressive components from environment mostly as ion inclusion in water as for Cl^- and SO_4^{2-}, and by ingression of CO_2, thus, resulting in progressive diffusion not only of the rebar protective layer in concrete, but also cause for the beginning of the chemical reactions that leads to mechanical deformation in matrix of concrete [10–12].

As stated in the works [13–14], the mechanism of rebar corrosion is mostly represented by electrochemical nature. That is considered, that passive state for steel corrosion to occur the current density must be below 0.1 $\mu A \cdot cm^{-2}$, and for the active state – over 1 $\mu A \cdot cm^{-2}$. However, speed of rebar corrosion cannot be adapted as linear progression due to the chemical influence on the cement composition of the concrete. The process of the electrochemical reaction in concrete itself include anodic dissolution of iron and cathodic reduction of oxygen [13]. Presence of needed pH and availability of oxygen near the steel rebar may cause the process of the reduction of water/proton. Therefore, it is possible to achieve electrical connection between anode and cathode in presence of the electrolytic environment for transferring ions in the solution (Fig. 1).

Inclusion of SO_4^{2-}, CO_2, Cl^- cause active state of corrosion in concrete. Not only they cause chemical transformations by creating semi- and fully soluble solutions with the cement compositions, such as: calcium hydrates, gypsum and hydro carbonates but also they are the main cause of acceleration of the rebar corrosion in active state [13]. Main aspects of corrosion mechanism graphically represented in fig. 2 and fig. 3 in work

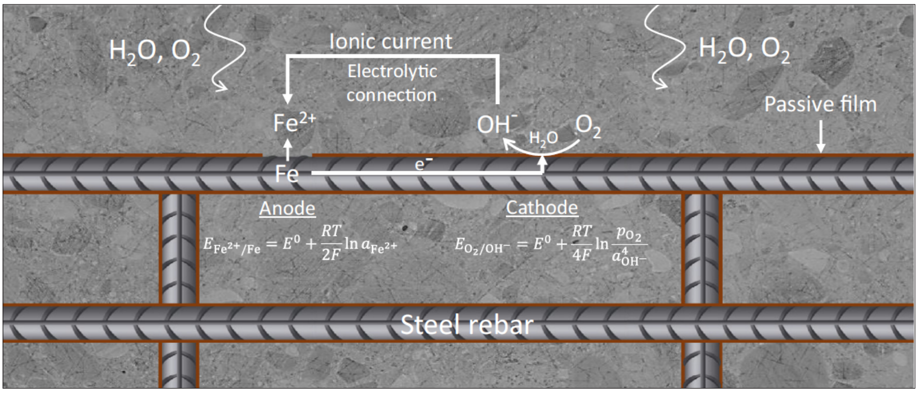

Fig. 1. Schematic representation of the corrosion of steel in concrete [13]

of authors [13]. For SO_4^{2-} environments, mechanisms of corrosion of the concrete are similar to the chloride induced environments [13–16]. Even though, environments that are consist with SO_4^{2-} might have inclusions of weak presence of Cl^- that comes from both the environment and concrete itself due to the chemical modifications of the slurry for achieving additional physical-mechanical properties.

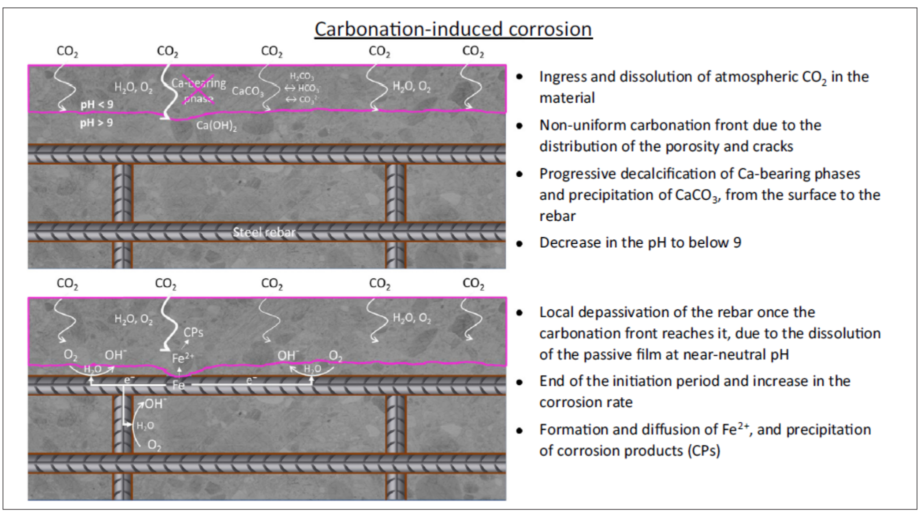

Fig. 2. Schematic representation of the carbonate induced corrosion in concrete [13]

Also, systematical inducing of aggressive components via moist through the thickness of concrete, as studied in the works of [17–18], the amount of impactful agents consistently changes due to the changes of the maintaining environment (i.e. rain, dry weather, high/low tides for sea constructions and etc.). Thus, as of the pH level in the system and its changeable ranges between high and low, this impact leads to the increase of hidratation processes wich leads also to exposure of the steel rebar. therefore, with lowering the pH – increase of speed of corrosion. Knowing all this changes and influences, it is consistent that both mechanical and chemical degradation

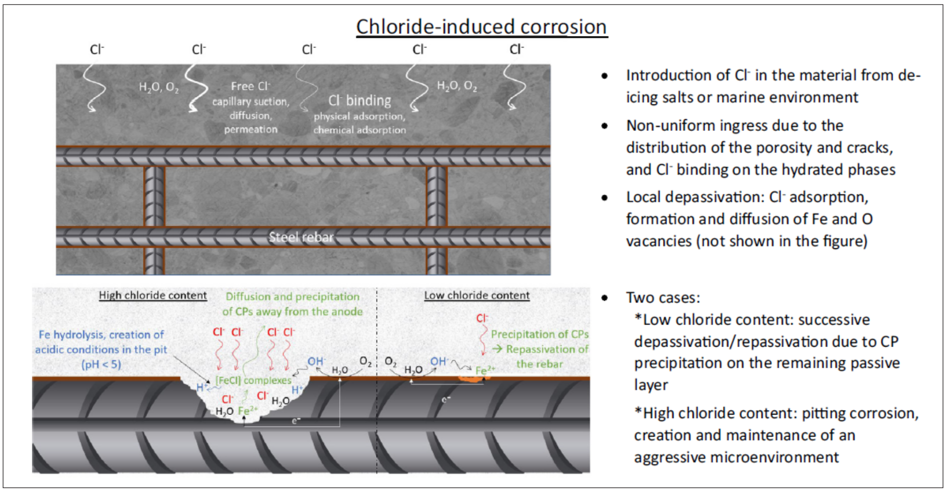

Fig. 3. Schematic representation of the chloride induced corrosion in concrete [13]

have place to occur in construction. Which is why to monitor stability of complex concrete constructions it is more preferable to use NDM methods to check on site without damaging the structure itself.

2. NDM electrical methods for monitoring of the corrosion rate

Most of the methods described in standards and generalized in works [13, 19–24] have their advantages and drawbacks that differently influence on the results of the received data.

Mostly emphasized monitoring technics are [13]:

– measurement of the corrosion potential;
– measurement of the concrete resistivity (by Wenner);
– measurement of the polarization resistance.

Those presented methods in general allow to emphasise directly to the corrosion rate of either rebar, concrete and monitor of the ingress rate of aggressive components from environment. Their advantages based on the:

– fast measurements;
– pointing out of the main defect point with high corrosion risk;
– providing of the insight on concrete durability;
– good agreement with gravimetric loss in case of active corrosion.

All of the methods based on the results that are provided by measurement tool consisted of two to four (sometimes five or more for advanced measurement technic [13]) electrodes. In the *measurement of the corrosion potential* electrodes placed one directly to the rebar and one on the wet sponge on the surface of concrete or embedded in the concrete. The drawbacks of the method are such that absolute value is highly affected by concrete conditions (geometry, resistivity, presence of cracks), composition of the pore solution (pH, chloride or sulphide content), the condition of the steel rebar (cathode-to-anode ratio), the availability of oxygen near the steel surface and environmental factors (RH, T).

Measurment of concrete resistivity is provided by injection of a direct or alternating current between the two outer electrodes and measurement of the resulting potential difference between the two inner electrodes. Usual monitoring parameters are values of frequency range in between of $0.5 < f(\text{kHz}) < 10$. Despite the possibility of identification of main degradation points of structure, absolute value is highly affected by concrete conditions (geometry, resistivity, presence of cracks), composition of the pore solution, environmental factors (RH, T), and the presence of the rebar. Yet, it is possible to improve the results by implementing Electrical resistivity tomography (ERT) that will allow to consider accurately the inherent heterogeneity of concrete and to account for the rebar effect in the measurement.

Measurement of the polarization resistance allows to get the linear sweep voltammetry in the anodic or cathodic direction around the corrosion potential in the value parameters of the Sweep rate = 10 mV min^{-1} and E_{corr} = ±10–20 mV. As in the measurement of the corrosion potential this method requires connectivity to the rebar. With visible advantages of this method, the challenging part is that sometimes measurements of the passive state of corrosion is overestimated. Therefore, slower sweep rate (< 2.5 mV min^{-1}) must be used must be used to improve the measurement of corrosion rate in this case [13].

Conclusions. Each of the methods presented in the review have potential of implementations of the onsite monitoring. Yet, combining of the non-destructive testing methods may in some way be challenging for the resulting values of the monitored indexes. Passive values of one method can be negative for others as in reverse wich leads to complexing of the received results in both of passive state and active. Visual monitoring must be implemented when using NDT methods to identify both initiation stages and propagation stages of corrosion on the structures. Thus, with accurate and systematic monitoring of the corrosion stages and comparing the results with constant values and known initial data the accurate assessment of corrosion rate can be measured.

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