THE REPAIR AND PROTECTION OF REINFORCED CONCRETE WITH MIGRATING CORROSION INHIBITORS

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ABSTRACT

The concrete is a very durable construction material and his use is based on the principle that concrete is an ideal environment for steel if properly proportioned and placed.
In general, reinforced concrete has proved to be successful in terms of both structural performance and durability. However, there are instances of premature failure of reinforced concrete components due to corrosion of the reinforcement.
Experience has shown that there are certain portions of exposed concrete structures more vulnerable than others.
Methodology for concrete repair it addresses to suggestions of the types of repair methods and materials and a detailed description of the uses, limitations, materials, and procedures for Repair of Concrete. At same the time the methodology presents recommendation on materials, methods of mixing, application, curing and precautions to be exercised during placement.
This work presents guidelines for managing reinforced concrete components and specifies the repair strategy with inhibitors incorporating.

Key words: reinforced concrete, steel corrosion, inhibitor, methodology

Introduction

Reinforcing steel embedded in concrete shows a high amount of resistance to corrosion. The cement paste in the concrete provides an alkaline environment that protects the steel from corrosion. This corrosion resistance stems from a protective ferric oxide film that forms on the steel when it is embedded in concrete. This film is stable in the highly alkaline concrete (pH approx. 11-13). The corrosion rate of steel in this state is negligible.

The passive film is not invulnerable, though. It can be damaged both chemically and mechanically.
Corrosion is defined as the deterioration of a material through a chemical or electrochemical reaction with its environment. For reinforcing steel in concrete, the steel will react with the chlorides and oxygen in its surroundings.
The corrosion of metal is a process that returns metal to its natural form. Steel is primarily made of iron. Iron oxide is the natural state of iron because it is more thermodynamically stable in this form.
The durability of reinforced concrete structures is limited as a result of the occurrence of reinforcement corrosion.

The protection of reinforced concrete structures from environmental influences and the extension of their operational life is one of the most important maintenance problems.

The term "concrete repair" refers to any replacing, restoring, or renewing of concrete or concrete surfaces after initial placement [1].

Traditional concrete repair technique involves many stages and costs associated. There aspects have been a driver for the development of innovative techniques, important in term of time and cost efficiency. One such technique is the use of corrosion inhibitors. These inhibitors are chemical compounds that reduce the corrosion rate of metals existing in actively corrosive environments.

Migrating Corrosion Inhibitor (MCI) technology was developed to protect the embedded steel rebar/concrete structure.

The methodology for concrete repair includes suggestions of the type of repair methods and the materials most likely to be successfully used. In the next place, the methodology contains a detailed description of the requirements with respect of handling, environmental conditions at time of application, mixing end application.

Methodology to repair damaged reinforced concrete using MCI corrosion inhibitors

1. General Requirements for a Quality Repair

No step in the repair operation can be omitted or improper performed without detriment to the utility of the work. Inadequate workmanship, procedures or material will result in inferior repair.

(1) Workmanship
Construction contractor or operation and maintenance team must repair imperfections or damage in concrete so that the repairs will be serviceable and of a quality and durability comparable to the adjacent portion of the structures.

(2) Procedures
Serviceable concrete repair can result only if correct methods are chosen and techniques are carefully performed.
Before repairs are commenced, the method and materials proposed for use should be approved by an authorized inspector.
Effective repair of damaged concrete structures cannot be ensured unless there is complete removal of all deteriorated or possibly affected concrete. Repair must be made at the earliest possible date.

(3) Materials
Materials to be used in concrete repair must be high quality, relatively fresh and capable to the meeting specification requirements for application. Materials selected to repair application must be used in accordance with recommendation of manufacturers. Mixing, proportioning and handling must be in accordance with the highest standards of workmanship

2. The concrete repairs system

2.1 Preliminary Inspection

This inspection comprises information about the design features of the structure as well as the materials of construction and environmental factors. Visible degradation detection and areas accessibility are the most important steps in the condition assessment process.

2.2 Detailed Inspection

The inspection in fact will contain a review of all visible degradations and all available information about the degradations of the structures: previous repairs, the aspect of reinforced concrete surface (efflorescence, rust, etc.), tension cracking, concrete surface damaged, visible reinforcement, structure deformation, moisture presence

2.3 In-situ investigations

Investigations program must contain the follow tasks:

- Structure significance;
- Nature, magnitude and intensity of phenomena;
- Costs;
- Accessibility;
- Environment.

A. The follow measurements are developed for reinforcements:

a) Concrete cover thickness measurement
Reinforcement cover is an important parameter in corrosion process. The measurement of this parameter can be developed by using commercially available equipment.

b) Assessment of corroding areas and corrosion risk evolution: potential measurements.

Corrosion is an electrochemical process and electrochemical measurement is one of the most important tools available for monitoring its progress.

c) Corrosion rate assessment
Corrosion concrete depends upon the ease of flow of the ions participating in the electrochemical process. The corrosion rates were evaluated from corrosion current density I_{corr}. The density of corrosion current I_{corr} can be calculated from the Stern–Geary equation [2].

$$I_{corr}= B/ R_p*A \qquad (1)$$

B is a constant and A is the polarization of surface.

Derived from Faraday's law, the following equation is applied to calculate the corrosion rate (CR).

$$CR\ (\mu m/y) = 304.2/R_p \qquad (2)$$

By periodic measurements of R_p it is possible to controls the evolution of corrosion process.

B. The measurements related concrete quality or aging degree is the follows:
a) Depths of carbonation.
In nuclear power plants, carbonation is most likely to occur at inside concrete surfaces exposed to relatively low humidity and elevated temperature. The extent of carbonation can be determined by treating a freshly exposed concrete surface with phenolphthalein (a pH indicator).

b) Resistivity measurements
Electrical resistivity of concrete could be an effective parameter to assess the risk of corrosion in reinforcing steel embedded in concrete especially for chloride induced corrosion. On the site, the resistivity measurements are used in parallel with potential measurements for obtaining corrosion diagnostic. This means that reinforced concrete with high resistivity will have a low corrosion risk.

c) Permeability measurements
Physiques properties of concrete, influences their permeability and the period of corrosion commencement. This type of measurement in situ is influenced by the concrete moisture, which limit their application.

2.4. Laboratory analyses

Chemical characteristics of reinforced concrete are determined by sampling core-samples. Global chemical analyzes is made on the soluble fraction from the insoluble sediment. Chloride dosage, sulphate dosage, sulfide dosage, etc., is made.

Mineralogical characteristics of concrete are determined by: optic microscopy, X-ray, etc.

2.5 Determine the Cause(s) of damage

The first and often most important step of repairing damaged or deteriorated concrete is to correctly identify the cause of damage. From a quick review of the common causes of damage reveals that the majority of them are of a continuing and recurring nature.

Has been identified multiples causes of damages: improper design, low quality materials or poor construction practice. All of these reduces the durability of concrete and increase its susceptibility to deterioration from other causes.

2.6 Evaluate the extent of damage

The next step of the repair process is to evaluate the extent and severity of damage. In this step, was assessed how much concrete has been damaged and how this damage will affect serviceability of the structure.

The most common technique used to extend determine of damage is sounding the damaged and surrounding undamaged concrete with a hammer. An indication of the strength of concrete can be determined by hammer blows. High strength concrete develops a distinct ring from a hammer blow and the hammer rebounds smartly. More detailed information can be obtained by using commercially available rebound hammer, such as the Schmidt Rebound Hammer. Other methods are: Petrographic examination of concrete, ultrasonic pulse velocity and acoustic pulse echo, acoustic emission, etc.

The areas of damaged concrete discovered by these methods should be mapped or marked to provide information needed in subsequent calculation of the area and volume of concrete to be repaired.

2.7. Evaluate the need to repair

Not all damaged concrete requires immediate repair.

Many factors need consideration before the decision to perform repairs can be made. With early detection, it may be possible to arrest the rate of deterioration using maintenance procedures. These steps- determining the cause of damage, the extent evaluating of damage and evaluating the need to repair- form the basis of what is known as a condition survey.

2.8. Select the repair Method

Once the above steps of the repair process have been completed, or upon completion of a detailed condition survey, the selection of proper repair methods and materials usually becomes very easy.

The repair and protection of concrete structures require relatively complex assessment and design. Introducing and defining by the key principles of repair and protection, EN 1504-9 helps owners and construction professionals to fully understand the problems and solutions throughout the different stages of the repair and protection process [3]. In Table 1 are represented the principles of repair and protection.

Table1 *Principles and Methods Related to Steel Reinforcement Corrosion [3]*

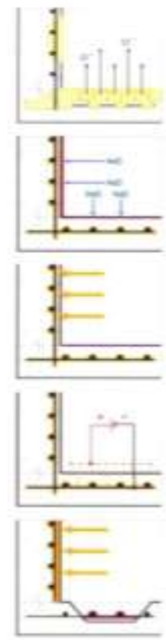
Principle	Description	Method	Basic diagram
Principle 7 (RP)	Preserving or restoring passivity	7.1 Increasing cover with additional mortar or concrete 7.2 Replacing contaminated or carbonated concrete 7.3 Electrochemical realkalisation of carbonated concrete 7.4 Realkalisation of carbonated concrete by diffusion 7.5 Electrochemical chloride extraction	
Principle 8 (IR)	Increasing resistivity	8.1 Hydrophobic impregnations 8.2 Impregnations 8.3 Coatings	
Principle 9 (CC)	Cathodic control	9.1 Limiting oxygen content (at the cathode) by saturation or surface coating	
Principle 10 (CP)	Cathodic protection Principle 11	10.1 Applying an electrical potential	
Principle 11 (CA)	Control of anodic areas	11.1 Active coating of the reinforcement 11.2 Barrier coating of the reinforcement 11.3 Applying corrosion inhibitors in or to the concrete	

Table 2 presents the methods that can be used for concrete and reinforcement protection.

Table 2 S*election of the methods to be used for reinforcement protection* [3]

Protection Requirements	**Minimal Level**	**Medium Level**	**High Level**
Carbonation	11.3 Applying corrosion inhibitors in or to the concrete	1.3 Coating 7.3 Electrochemical realkalisation of carbonated concrete 7.4 Realkalization of carbonated concrete by diffusion	11.3 Applying corrosion inhibitors in or to the concrete and 1.3 Coating 7.3 Electrochemical realkalization of carbonated concrete and 1.3 Coating
Chloride	1.1 Hydrophobic impregnation 1.2 Impregnation	11.3 Applying corrosion inhibitors in or to the concrete and 1.1 Hydrophobic impregnation 11.3 Applying corrosion inhibitors in or to the concrete and 1.3 Coating	7.5 Electrochemical chloride extraction and 1.3 Coating 7.5 Electrochemical chloride extraction and 11.2 Barrier coating of the reinforcement 10.1 Applying an electrical potential

2.9. Prepare the Old Concrete for Repair.

Preparation of the old concrete for application of the repair material is of primary importance in the accomplishment of durable repairs. It is essential that all of the unsound or deteriorated concrete be removed before new repair materials are applied.

a) Saw Cut Perimeters. The first step in preparing the old concrete for repair is to saw cut the perimeter of the repair area to a depth of 1 to 1.5 inches (2.5 -3.8 cm).

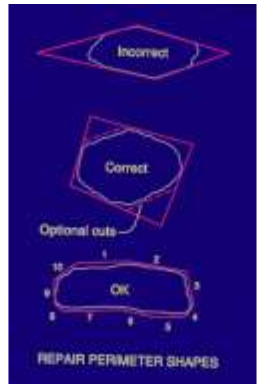


Figure 1

Saw cut patterns for the perimeters of repair areas [1].

The saw cut perimeters should have rounded corners, as seen in figure 2, whenever reasonable. Rounded corners cannot be cut with a circular concrete saw, but the cuts can be stopped short of the intersection and rounded using a jackhammer or bush hammer carefully held in a vertical orientation.

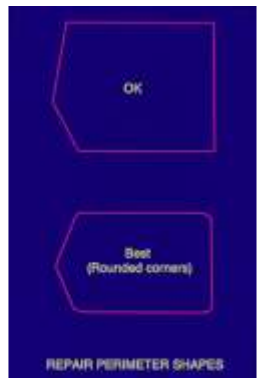


Fig. 2

Corners of repair areas should be rounded whenever possible [1].

b) Concrete Removal. All deteriorated or damaged concrete must be removed from the repair area to provide sound concrete for the repair material to bond to.

c) Reinforcing Steel Preparation. Reinforcing steel exposed during concrete removal requires special treatment. As a minimum, all scale, rust, corrosion, and bonded concrete must be removed by wire brushing or high pressure water or sand blasting.

d) Maintenance of Prepared Area. After the repair area has been prepared, it must be maintained in a clean condition and protected from damage until the repair materials can be placed and cured.

2.10. Apply the Repair Method.

The overall protection required for concrete structures as well as that required for their embedded steel reinforcement, is dependent on the type of structure, its environmental exposure and location, its use and the selected maintenance strategy. Therefore, protection proposals should be adapted to individual structures, their specific conditions and their specific requirements.

Traditional repairs involved many stages including removal of damaged and contaminated concrete, preparation and treatment of reinforcement, patch repair with pre-bagged cementitious repair mortar, reprofilling concrete surfaces with leveling mortar and, perhaps, application of a protective coating. This aspect has been a driver for the development of more stringent specifications for new works and innovative techniques for repair of reinforced concrete. Innovative techniques include desalination, re-alkalization and the use of corrosion inhibitors. The use of corrosion inhibitors should provide a cost effective solution if used in appropriate circumstances and as part of an integrated repair strategy that controls safety risk.

Optimum repair strategy for a structure, and presents the overall process proposed which involves a number of stages. These include:
• Identify the maintenance need, typically based on inspection reports;
• Formulate a clear set of objectives of what any remedial treatment is designed to achieve.
• Identify a range of potential remedial strategies based on the assessments of the current condition of the structure and the objectives of the maintenance;
• Specify the decision making criteria such that the reasoning behind the final decision, or range of options, can be clearly presented in relation to the defined objectives and can be independently reviewed;
• Select preferred option based on the technical and non-technical factors of relevance in the objectives for the repair.
• Control of risk where the preferred option is innovative may involve specification of particular action
• Rank project for comparison with other projects.
• Apply repair technique(s). Table 3 shows the mix proportions for the repair materials [4]

Table 3 *Mix proportion for the repair materials [4]*

Materials	**Gravimetrical**	**Volume**
	Kg/m^3	**parts**
Cement **CEM II/A-S 32,5 N-LH**	675	1
Sand 0-3mm	650	0,75
Sand 3-7mm	650	0,75
Water	230	0,45

Mixing procedure generally was as follows [5]:
1. Wet the inside of the drum. Drain all excess water from drum.
2. Add all coarse and fine aggregate and mix for 1.5 minutes.
3. With mixer running, add approximately 85% of batch water (with inhibitor) to mixer and mix for 2.0 minutes.
4. Add all cement over a 1.0 minute span and then mix for an additional minute.
5. Stop mixer and scrape drum (over an approximately 1.0 minute span). Restart mixer.
6. Add remaining batch water (with inhibitor as needed. Mix for 2.0 minutes.
7. Stop mixer and let stand for 2.0 minutes.
8. Restart mixer and mix for 2.0 minutes.
9. Fills completely repaired zone.

2.11 Curing and protection.

Proper curing is essential for a successful dry-pack repair. The surface of the repair area will be protected from drying and shall be kept continuously moist for 14 days.

2.12 Post-repair management of service life

The best way to manage the service life of any repaired structure is to monitor its performance.
Comprehensive corrosion monitoring involves collecting data from tests using equipment such as electrical resistance probes or linear polarization techniques, with embedded or surface mounted probes.

The monitoring of corrosion performance plays a huge role in determining the effectiveness of corrosion inhibitors.

Conclusions

Experiences of repairs, supported by field studies of repaired structures, confirm that a principal cause of damage to reinforced concrete structures is corrosion of the reinforcement.

Experience gained during repair projects, and extensive field studies of repaired structures, show that the effectiveness of the concrete repair is dependent on:

- Correct diagnosis of the cause of the damage;
- Selection of a repair strategy that addresses this cause;
- Choice of appropriate repair materials and methods;
- Careful management of the process;
- Post repair maintenance strategy supported by comprehensive records.

References

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