

Supplementary material

Durability performance assessment of non-standard cementitious materials for buildings: a general method applied to the French context

Fact sheet 3 - Risk of corrosion of metallic elements

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1 Introduction

This fact sheet covers cement products whose ability to protect metal elements (reinforcements, inserts) from corrosion remains to be tested. We are going outside of conventional techniques, because no sufficient information is available to determine the passivation of submerged metallic elements in such conditions. Products may include metals whose behaviour in traditional concrete is not fully understood, or regular steel in cement matrices with a particular chemistry (low pH concrete, etc.). It is therefore important to directly assess corrosion risk without considering an initiation phase. The product is therefore considered in its initial state, unmodified by any possible carbonation or by the penetration of chlorides. For corrosion risks caused by carbonation or chloride ion penetration, please refer to those specific pathology sheets.

2 Consequences

- Reduction of reinforcement cross section.
- Cracking, spalling of the concrete cover.
- Loss of bond between the concrete and the reinforcements.

- Loss of load-bearing capacity of the reinforced structure (in extreme cases).

3 Physiochemical mechanisms

The corrosion of reinforcements is caused by a chemical reaction between the metal conductor and its aqueous environment. The main mechanisms involved (Figure 1) are described below.

- Corrosion occurs in the simultaneous presence of an oxidation reaction of the metal (anode) and a reduction reaction of oxygen (cathode).
- The rate of the electrochemical reactions taking place where the reinforcement and the concrete meet increases along with water content and decreases beyond a certain value due to falling oxygen diffusion.
- Redox reactions are followed by secondary reactions that form corrosion products (oxides and oxyhydroxides) on the surface of the metal.
- The nature of the environment surrounding the reinforcements (pH, temperature, resistance of the concrete's interstitial solution, chloride content, oxygen content, aggressive or inhibiting agent content,

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etc.) changes the local thermodynamic equilibria and kinetics of redox reactions.

- Corrosion products are more or less stable and may in some cases continue to be formed until the reinforcement has corroded completely.
- In the case of steel, the corrosion products of iron that form on the steel's surface expand. This expansion creates internal stresses that promote the formation of cracks in the concrete surrounding the reinforcements.
- Cracks that reach the surface of the concrete significantly accelerate the diffusion of oxygen and water.

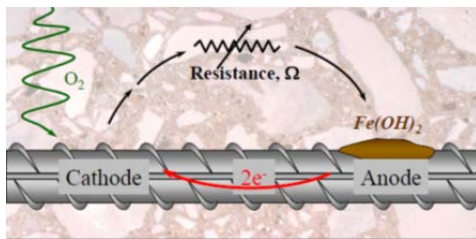


Figure 1. The basic mechanisms of steel corrosion in concrete.

4 Main models

- There is no agreed upon model (as of 2015) for predicting the corrosion of reinforcements.
- For example, the CORDOBA model [1] includes the transport of water and oxygen, the oxidation of steel, and mechanical factors.

5 Influential parameters

Material parameters:

- The concrete's ability to maintain an elevated pH in its interstitial solution over time, which keeps the metal in a stable state with a protective surface layer (the "passive" film).
- The concrete's microstructure (permeability and diffusivity) controls the ingress of water, oxygen, and other components that may increase corrosion rate.
- The type of metal.

Environment parameters:

- Relative humidity, rain, wind, sun exposure, temperature, and more generally the surrounding environment create fluctuations in the relative humidity and water content at the metal/concrete interface.
- The concentration of oxygen and other elements such as chlorides can increase corrosion rate (this is also true of the interstitial solution's conductivity).

6 Testing method stages

The testing method's key steps include:

- Preparing the electrodes (initial state of corrosion, cleanliness, attention paid to the electric connections, proper cover distances).
- Adjusting the environment's relative humidity and oxygen concentration (near to normal atmospheric oxygen concentration).
- Creation of a gaseous or liquid medium that represents the environment (anion content, i.e. chlorides, sulphates, etc.).

The quantities of interest may include:

- indicators such as the reinforcement corrosion potential [2] and concrete resistivity [3],
- polarisation resistance, which allows for the calculation of instantaneous corrosion rates [4],
- surface analyses to describe the homogeneity of the corrosion of the reinforcements submerged in the concrete at the end of the test.

Each of these quantities requires specific calibrated thresholds so as to assess the service life of reinforced structures.

7 Standard testing methods

Tests generally consist of taking electrochemical measurements of reinforced concrete as function of the ageing duration in their environment. These methods are fast (i.e. only a few minutes long). Therefore, the duration of the test is determined by the chosen ageing duration.

Additionally, submerged metallic elements may be extracted from the cement material after a certain period of time has passed for observation or analysis to verify the absence of corrosion products (experimenters often talk about sample "autopsies" in this instance).

Name	Environment	Laboratory or field conditions	Quantity of interest	Comments
NF EN 480-14 [5]	20 ± 2 °C, saturated calcium hydroxide solution	Laboratory	Maximum current density ($\mu\text{A}/\text{cm}^2$) after applying constant potential and visually inspection of the reinforcement at the end of the test	The sample containing the additive is compared with a control sample without the additive in order to assess the additive's effect on the corrosion process.
ASTM C876 [6]	Natural atmospheric environment	Laboratory conditions or field conditions	Corrosion potential Measure the potential difference between the reinforcement and the reference electrode placed in contact with the concrete's surface	Test requires a specialist intervention or supplementary data (chloride content, carbonation depth, etc.) to reach conclusions about service life of structures. There is work disproving this method for slag concrete
RILEM TC-154 EMC[3]	Measured in an atmospheric environment	Laboratory conditions or field conditions	Concrete resistivity Different principles play into these recommendations: 4-point method, method equivalent to ASTM C876 and other studies	Concrete resistivity measurements are generally correlated with chloride and water content. Information about reinforcement corrosion should be obtained using other methods.
CERIB Protocol [7]	Reproduction of the environment (humidity, drying, carbonation and/or chlorides, etc.) The reinforcement, the working electrode, and the reference electrode are submerged in the concrete	Laboratory	Corrosion potential and polarisation resistance	Comparative tests with a standardised control concrete are recommended.

8 Performance assessment

Assessment method:

- "comparative" assessment: the quantity of interest is measured for the candidate concrete, then compared to the values obtained from a standardised reference product using the same testing method.
- "absolute" assessment: currently, there is no absolute threshold value that has been defined in a sufficiently robust manner, some documents (ASTM C876 [6], RILEM TC-154 EMC [2-4]) list thresholds that are not agreed upon for all binders.

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