

Measuring, understanding, and forecasting reinforcing steel corrosion in concrete

Ueli Angst^{1,*}

¹ Institute for Building Materials, ETH Zurich, CH-8093 Zurich, Switzerland

Abstract. This contribution reviews recent advances in the areas of measuring, understanding, and forecasting reinforcing steel corrosion in concrete. The overall goal is to promote scientific discussion and progress to allow for technological innovations in the fields of non-destructive testing, structural health and corrosion monitoring, as well as modelling of the performance of reinforced concrete structures and maintenance strategies in actual service environments. *Improved Condition assessment as well as Concrete Repair, Rehabilitation and Retrofitting* (ICCRRR) technologies are needed to face the challenge of ageing infrastructure and to meet the “net zero by 2050 target”.

1 Motivation

Corrosion of reinforcing steel in concrete is the primary cause for the degradation of civil infrastructure [1]. It is a common challenge of the industrialized countries that the asset of structures contains an increasing portion of relatively old structures, which need to be maintained to ensure safety and availability. Projections for the number of structures needing repair in the coming decades are in the order of an increase by a factor of 3–5 by 2050 with respect to now [2]. Already today, however, leading industry nations are confronted with the need to close bridges for heavy traffic due to safety concerns, and – fortunately more rarely – cases of structural collapses.

Against this background, there is an urgent demand for *Improved Condition assessment as well as Concrete Repair, Rehabilitation and Retrofitting* (ICCRRR) technologies. Without technological progress, it will be extremely difficult to tackle the challenge of ageing infrastructure.

Another concern relates to the pressing issue of global warming and the need to reduce the construction sector’s environmental footprint. Ambitions such as the “net zero by 2050 target” call for dramatic changes in both the materials used (e.g. low-emission cements, recycled mineral waste and aggregates) and construction processes (e.g. digital / additive construction). Such new technologies not only needed to have a low environmental footprint at the time of construction, but to prove durability over long time scales.

For the reasons given above, it is vital to be able to measure, understand, and forecast corrosion of steel in concrete. This contribution will highlight recent advances in these three areas and how they can contribute to address the societal/environmental challenges outlined above.

2 Measuring corrosion

The measurement of corrosion means that corrosion processes can be followed and quantified in both laboratory studies and, more importantly, in-situ in structures. While a number of techniques have been developed that may allow for the detection of corrosion-onset and the quantification of corrosion rates under certain well-controlled conditions – in particular, specially designed samples in the laboratory (e.g. segmented bars for macro-cell corrosion studies [3, 4]) – reliable measurements of corrosion processes under actual exposure conditions in structures are still a major challenge. Such quantification, however, is crucial for the understanding of corrosion processes, as existing models need to be expanded to better take into account the dynamic behaviour under generally time-variable exposure conditions [5, 6].

New opportunities may be seen in recent advances in sensing technologies, allowing for the placement of embedded sensors to characterize environmental changes such as chloride concentrations and pH during the life of a structure [7]. Such sensing techniques not only allow for a better characterization of the exposure conditions but also to relate corrosion

* Corresponding author: uangst@ethz.ch

processes to the actual changes in the pore solution chemistry.

Additional opportunities for the in-situ quantification of corrosion rates, especially for localized corrosion, are related to combining advanced numerical corrosion models with on-site measurements, such as [8]. Here, the progress in computational power may facilitate the development of a new generation of non-destructive techniques.

3 Understanding and forecasting corrosion

One of the prevailing key open questions is related to the factors that lead to corrosion of steel in concrete in chloride-exposure environments. Various assessments have revealed that the concept of the critical chloride threshold is not adequate in scientifically explaining corrosion initiation [6]. A number of studies have highlighted that different features at the steel-concrete interface play important roles [9-11]. Nevertheless, it is still not possible to reliably predict the initiation of corrosion.

Similarly, the rate at which corrosion processes occur is an important parameter, especially for the assessment of the life or residual life of a structure. Recent fundamental understanding about the relevance of concrete microstructure and moisture [12] opened new perspectives, both for the decarbonization of cement and concrete and for new models to forecast the performance of reinforced concrete. Such models may also be useful on implementing and generating confidence in repair and rehabilitation methods deviating from mainstream approaches, such as the use of concrete surface treatments [13]. Nevertheless, more research is needed to develop engineering models that can reliably predict the rate of corrosion of steel in concrete under actual exposure conditions and on the basis of parameters available in engineering practice.

Finally, corrosion-induced concrete cracking and spalling is a common limit state in engineering practice, but so far no model is available to reliably predict this [14]. This may be related to the fact that most models are centred on mechanical considerations, e.g. on the basis of the assumption of a rebar idealized as an expanding cylinder. On the other hand, little attention is paid on the transformation of dissolved ferrous ions in the pore solution, resulting from (electro-)chemical reactions, including considerations of the thermodynamic stability and the kinetics of different reactions in competition with

transport. A recent compilation of literature data on the speciation of iron in cementitious systems [15] may be a useful starting point in this regard, but certainly more scientific studies are needed to fully reveal the “fate” of dissolved iron in a cementitious matrix.

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