78TH RILEM WEEK & RILEM CONFERENCE ON SMART MATERIALS AND STRUCTURES: MEETING THE MAJOR CHALLENGES OF THE 21ST CENTURY SMS 2024 – IMPACT OF CRACKS ON CHLORIDE-INDUCED REINFORCEMENT CORROSION

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Abstract

Current codes mandate restricting surface crack width to enhance structural service life by mitigating reinforcement corrosion. The rationale behind this approach is the assumption that limiting surface crack width can prevent or delay corrosion, thereby preserving structural integrity. However, the influence of surface crack width on durability is complex and still debated. It is generally accepted that, in chloride-rich environments, the presence of transverse cracks poses a substantial risk as it can lead to pitting corrosion. Pitting corrosion, characterized by local reductions in bar diameter, significantly compromises the load-carrying capacity and ductility of the structure. A recent study [1] shows, however, that corrosion pits may grow at a slower rate over time while increasing in number. Numerous, scattered, shallow pits are less detrimental to the structure than a few deep, narrow pits. This work focuses on designing long-term experiments that will allow for a deeper understanding of the complex relationship between surface crack width and corrosion patterns. The study is based on identified knowledge gaps in the existing experimental data, and specifically looks into the influence of concrete cover, concrete quality, and average crack spacing, on the corrosion distribution in the presence of transverse cracks.

Keywords: Corrosion damages, concrete, cracks, crack width.

1. INTRODUCTION

Corrosion poses a persistent threat to reinforced concrete structures. Despite the inherent protective properties of the alkaline concrete pore solution, exposure to chloride-rich environments and/or carbonation inevitably accelerates the corrosion process of reinforcement bars. The degradation process begins with the depassivation of the bars and progresses over time, ultimately resulting in significant structural deterioration [2].

In current codes and engineering practices, surface crack width is limited to mitigate the effects of corrosion. Empirical and semi-empirical formulas are used to predict crack width under diverse loading conditions. Maximum allowable crack width values are specified for different exposure environments, aiming to minimize the likelihood of corrosion in reinforcement bars [3]. However, it's crucial to acknowledge that numerous factors beyond concrete crack width exert influence on the risk of corrosion [1].

The new EC2 [4], which is to be gradually introduced into practice, makes a notable advancement by prescribing different concrete covers tailored to exposure, design service life and concrete quality. A novel addition to this standard is the definition of “concrete corrosion resistance” based on chloride ingress in uncracked concrete. This approach permits a smaller concrete cover when employing concrete with low chloride ingress, thereby acknowledging the pivotal role of concrete quality in mitigating corrosion damage.

While it may seem intuitive that impeding chloride penetration delays the onset of corrosion, the implications become less clear when considering the inevitability of concrete cracking. Cracks serve as more direct pathways for chlorides to reach the reinforcement bar: it is generally accepted that corrosion pits are likely to form in proximity of transverse cracks [1]. When the concrete cover decreases, so does the path for chlorides to reach the bar at the crack, thus, the formation of corrosion pits at the crack is expected to start earlier than in a specimen with a large concrete cover, independently of the concrete quality. In addition will both cracks and a small concrete cover lead to a more variable moisture load affecting the chloride threshold for corrosion [5] and the subsequent corrosion rate [6].

Conversely, a reduced concrete cover might accelerate the formation of corrosion-induced cracks once the corrosion process commences, thereby increasing the extent of bar exposure to oxygen and propagating the damage towards more general, and less dangerous, corrosion pattern.

In a recent study by the authors [1], it was shown that in the presence of transverse cracks, corrosion pits were more prone to increase in quantity rather than size over time. Additionally, no discernible correlation was observed between corrosion damage and surface crack width. Building upon this research, the present work endeavours to conduct long-term corrosion tests, exploring various concrete compositions, crack spacing and cover thicknesses. Results are also to be used to complement an existing database compiled from literature, which will allow the use of statistical analyses to further look into the relationship between corrosion damage, transverse cracks, and surface crack width.

2. CONSIDERATIONS ON THE EXPERIMENTAL PROGRAM

The experimental program is planned in accordance with existing recommendations [7] and drawing from the authors' prior experience. The aim is to execute long-term laboratory experiments documenting cracks and corrosion characteristics in well-defined laboratory specimens. The study is to focus on chloride-induced natural corrosion (i.e. not using induced currents). The reinforcement concrete specimens are to be pre-cracked and exposed to a solution of salt and water; measurements of the ongoing corrosion process are to be taken through the entire duration of the study.

The experimental program is designed to close gaps found in earlier research. Specifically, the availability of data in literature with certain combinations of concrete quality, average crack spacing, and concrete cover is scarce [1]. Thus, the preliminary plan for the experimental program target four specific combinations:

- Specimens with large concrete cover and small average crack spacing, and small concrete cover and large average crack spacing.
- Specimens with good concrete quality and small average crack spacing, and low concrete quality and large average crack spacing.

These combinations are chosen to ensure that the experiments will complement the data available in existing literature [1].

It is important to notice that the variability in average crack spacing is mechanically coupled with the geometry of the specimens. Most of the available experiments are conducted on relatively small beams which are first pre-cracked in bending. Designing a specimen of such type with small concrete cover and large average crack spacing can be challenging without the use of notches, or other methods to induce cracks, since average crack spacing decreases with concrete cover. Additionally, average crack spacing is seldom considered as a separate parameter, and thus left to vary with the designed concrete covers. However, the combination of small concrete cover and large average crack spacing is relevant when the outcomes of small-scale experiments are applied to larger scale structures, particularly in the context of older structures, which typically have a small concrete cover.

One further requirement for the experimental program is for the concrete samples to be reasonably small. This is to facilitate the use of X-ray tomography. X-ray tomography has been effectively utilized in recent research to investigate corrosion products [9][10]. By scanning the samples multiple times during the corrosion process, it is possible to observe the evolution of corrosion products over time, particularly at the slip and separation zones, and interfacial voids. Collecting data at various intervals allows for both short-term and long-term measurements without the need to destroy the specimens, which has, until recently, been a limiting factor in corrosion studies. Furthermore, X-ray tomography allows to collect specially defined data before the extraction of the reinforcement bar to oxygen: since corrosion products react with oxygen when exposed to air, it is often a challenge to define the volume of corrosion products at the extraction of the rebars. A desired outcome of the study would as well include acquiring data on corrosion patterns before and after the formation of corrosion-induced cracks.

This said, no matter the many advantages of X-ray tomography, it has its limitation [11], and it may become unfeasible to collect and analyse image data for every single specimen, if an elevate number of specimens is to be cast. Moreover, in engineering practice, the possibility to use X-rays to monitor corrosion development is, nowadays, quite a remote option. Therefore, it is important that a second method to measure corrosion development is used, thus additionally allowing to compare imaging data to a more traditional method. A three-electrode setup is seen as a possible option, however, other methods [7] are still under consideration.

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