Modelling of deterioration processes in concrete structures plays an increasing role in the design of reinforced concrete structures. Large sums are spent every year to ensure the durability of concrete structures, especially towards reinforcement corrosion. Improved durability provides increased structural reliability, economical improvements in form of less need for maintenance and repair as well as increased sustainability due to an increased energy and resource efficiency. Several service life prediction models dealing with reinforcement corrosion in concrete structures can be found in the literature. However, the applicability of these models to determine the service life of concrete structures in aggressive environments needs to be investigated as the majority of the models a) assume an initial pristine state of the reinforced concrete structure neglecting the presence of cracks and other defects and b) define the end of service life once reinforcement corrosion is initiated neglecting corrosion processes during the propagation stage.

The goal of this work was to develop a framework for the service life prediction of reinforced concrete covering initiation and propagation of chloride-induced reinforcement corrosion. The framework includes coupled models describing transport of various substances and corrosion of reinforcement in cracked and uncracked concrete. The framework further allows for subsequent prediction of corrosion-induced mechanical damages.

To describe the transport of various substances in concrete a heat and mass transport model was applied, which is based on thermodynamic principles. To incorporate the influence of temperature and chloride on the moisture sorption extensions were made using experimental results. The impact of chlorides on the moisture sorption was accounted for using experimental data available in the literature. To quantify the impact of temperature on the moisture sorption experimental investigations were undertaken by means of time domain reflectometry (TDR), in which concrete specimens were subjected to varying temperatures. Using TDR measurements in combination with multi layer adsorption theory, it was shown that it is possible to quantify the impact of temperature on the moisture sorption of cementitious materials to a large extent. To incorporate the impact load-induced cracks have on the ingress, a simplified crack geometry was used, which may be divided into two parts; 1) a coalesced crack length that behaves as a free surface for moisture ingress, and 2) an isolated micro-cracking length that resists ingress similarly to the bulk material. The ability of the applied transport model to simulate the moisture ingress in cracked and uncracked concrete specimens was demonstrated comparing experimental ingress results and numerical simulations.

The corrosion model, which is coupled to the transport model, was used to describe electrochemical processes at the reinforcement surface. The corrosion model was based on generally accepted physical laws describing thermodynamics and kinetics of electrochemical processes. The applicability of the model to capture various reinforcement corrosion phenomena, such as activation, resistance, and concentration polarisation as well as the impact of temperature and relative humidity was demonstrated comparing experimental data and numerical simulations. In addition, experimental investigations were carried out to study the impact of load-induced cracks on the risk of reinforcement corrosion. Instrumented rebars, developed in a previous study, were used to assess the potential for initiation of corrosion along the reinforcement surface. Good correlations were found between the extent of separation between concrete and reinforcement and the risk of corrosion along the reinforcement surface, which supports earlier observations on the detrimental impact of the concrete-reinforcement interfacial condition.

To describe corrosion-induced mechanical damages a thermal analogy was used modelling the expansive nature of solid corrosion products. Input for the mechanical model was the corrosion rate predicted by the corrosion model. The mechanical model further accounts for the penetration of solid corrosion products into the available pore space of the surrounding cementitious materials. Based on x-ray attenuation measurements a concept describing the penetration of solid corrosion products was developed. The capability of the mechanical model to simulate corrosion-induced concrete cracking was shown comparing numerical simulations with experimental data obtained from accelerated corrosion tests. During this Ph.D. study, the framework for the service life prediction of reinforced concrete was established and the individual models tested comparing laboratory data and numerical simulations. However, for a validation of the framework combining all models additional (in-situ) investigations are required.

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