Abstract

The chloride-induced corrosion of reinforcement is the main reason for repair of concrete components in traffic infrastructure. Two stages of the deterioration process may be distinguished: initiation and propagation. Consequently, prediction models for the durability mostly comprise two parts as well. The first one describes the chloride ingress into the concrete during the initiation stage, while the second one models the following propagation stage. Many models for the chloride ingress assume a more or less homogeneous process and are based on diffusion as the only transport mechanism. The application of these models for the description and the prediction of chloride ingress is restricted to conditions where the concrete is permanently wet. These models are not valid for concrete in splash water exposure conditions. However, such conditions are dominant in road environment, where the chloride ingress is not homogeneous at all. The primary goal of the present work was to obtain detailed knowledge of the physical processes, which occur during the water absorption and the chloride ingress. In particular, the observed discrete incidents, within which water and chlorides enter into the concrete in a short time, were described and defined. Further, a proposal for the modelling of chloride ingress in splash water environments was developed.

The goals were reached by combining an extensive field study and investigations in the laboratory. The behaviour of different concrete mixtures was compared in the field study, which laid the basis for the analysis of the influence of various exposure conditions. The online-monitoring allowed a detailed survey and to study the processes in-situ. From the analysis of the changes of the water content in the concrete, the build-up of the chloride profiles could be investigated and finally an appropriate model could be developed.

Different incidents have been observed which determine the water content of concrete in a splash water exposure. Capillary suction and evaporation are the most important transport mechanisms during these incidents. Both of these processes proceed simultaneously and they seem to influence each other. Due to the evaporation, the in-situ water absorption as a result of capillary suction gets retarded compared to the absorption in a suction test performed in laboratory. But there are certain climatic conditions, which reduce the capability of the evaporation. For certain time periods, a situation may develop for which in-situ and laboratory water absorption rates are very similar. Such situations occur for combinations of high relative humidity and low temperature. Thus, large uptakes of water are expected only during wintertime. From March to November, the absorbed amounts are small and limited at a boundary layer of 5 to 10 mm. In this period of the year, the concrete desiccates slowly from the outside inwards. The volume of absorbed water is determined by the concrete properties and its water content at the time before the incident, providing optimal climatic conditions are present.

The incidents were categorised as large, medium and small ones according to their effects on the water content of concrete. They were characterised by the depth of water ingress. This criterion is independent of the type of exposure of the concrete and its quality. While the humidity of the concrete reaches its initial state between 2 to 4 weeks after a medium incident, the large incidents may have a long-term effect lasting for several months. That means, that the large incidents become important not only when considering the chloride ingress, but also for the corrosion rate.

The nature of the water ingress is a decisive factor for the chloride ingress, which happens during wintertime. Similar to the water ingress, the chloride ingress proceeds very fast, within periods of a few days, due to capillary suction. The corresponding volume of chlorides and the depth of its ingress were evaluated for the different incidents and, considering the different transport mechanisms, a simple model was proposed for the build-up of the chloride profiles: During wintertime, the chlorides reach the outer layer of the concrete due to capillary suction. The chlorides are accumulated there and may be transported deeper into the concrete by capillary suction. Irrespective of the climatic season of the year they are redistributed inwards and eventually outwards by diffusion, with respect to the present concentration gradient. The contribution of the capillary transport may be determined based on the suction behaviour of a particular concrete mix and the exposure conditions. The redistribution of the chlorides has been calculated using the chloride migration coefficient from a laboratory migration test and the corresponding solution of Fick's second law. The model includes the most important phenomena that influence the chloride ingress in a splash water environment. All the factors, that may have an influence on them, can easily be taken into account. Hence, it enables to improve the predictions of the build-up of chloride profiles in concrete.

The combination of in-situ measurements (e. g. electrical resistance, chloride content) and laboratory tests has shown to be an appropriate method for the analysis of the changes of water content in concrete and provided the basis for the modelling.

Assuming a similar rate of capillary pores, concrete mixtures with coarser pores absorb water faster, and dry out faster as well, than concrete mixtures with finer pores. That means that the sustainability of an incident is smaller in a concrete with coarser pores and an additional absorption of water is possible again in shorter time. As a result, a larger volume of water and also more chlorides are taken up in the same exposure (for example the concretes with w/c = 0.50, with fly ash and with slag). The reverse was found for concrete with silica fume, it took up rather smaller amounts compared to its rate of capillary pores. The positive effect of a low w/c-ratio with regard to the water and chloride ingress was clearly shown. The mass of bound chloride was high in all concrete mixtures. Up to a total chloride content of about 2 % per cement mass, it was between 63 to 85 %. Distinctive lower corrosion rates may be expected in concretes with mineral additions due to their higher electrical resistance, especially in the case, in which the concrete mixtures dry out during summertime. The differences in the behaviour of the various concrete mixtures become smaller with increasing water content during wintertime.