DTU Civil Engineering
Department of Civil Engineering

DANISH TECHNOLOGICAL INSTITUTE

DANISH EXPERT CENTRE FOR INFRASTRUCTURE CONSTRUCTIONS

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The Danish Expert Centre

The Danish Expert Centre for infrastructure constructions was established ultimo 2010 as a performance contract signed between the Danish Ministry of Science, Technology and Innovation and the Danish Technological Institute.

The contract runs until the end of 2012 and involves a close cooperation with DTU Byg (Technical University of Denmark).

The main purpose is to establish a platform for cooperation between the two leading technological institutes in Denmark with respect to durability and service life of reinforced concrete structures in aggressive environment.

Service Life

Most of the major reinforced concrete structures for infrastructural purposes in Denmark are exposed to marine environment and/or are subjected to periodic action of de-icing salts in the winter season.

The most important degradation mechanism of these structures is chloride induced reinforcement corrosion, which ultimately leads to loss of mechanic properties of the structure.

The service life of a reinforced concrete structure in marine environment or subjected to de-icing salts is typically described by two stages: 1) the initiation and 2) the propagation period.

1) The initiation is defined as the time taken from initial exposure to the aggressive environment until a concentration of chloride at the depth of the reinforcement able to initiate corrosion, has been reached.

2) The propagation is defined as the time that the structure still meets the service requirements after corrosion has been initiated, without extensively high maintenance costs.

Many different models for predicting the service life of reinforced concrete structures exist. Most commonly, these are based on predictions from the extrapolation of chloride ingress profiles measured by accelerated testing of a specific concrete. Common to most, if not all service life prediction models is that they cannot accurately predict the performance of a concrete without previously carrying out extensive measurements.

There is no doubt among concrete experts that the degradation of a reinforced concrete structure is an extremely complex process, where a large number of factors play a significant role. Nevertheless, research in understanding the basic mechanisms of chloride ingress should not be neglected, since establishment of sound, quantitative models substantially reduce the amount of experimental work required.

Consequently the Danish Expert Centre for Infrastructure Constructions is focusing on the understanding and quantification of chloride binding, corrosion initiation, and corrosion and crack propagation, which will form a platform for the future development of an advanced service life model.

A service life prediction tool for concrete constructions in marine environment or subjected to de-icing salts must basically include three topics (Figure 1): transport of aggressive ions through the concrete cover and their interaction with concrete, initiation and propagation of corrosion, and mechanic behavior of the concrete cover and structure as corrosion propagates.

Reference group

In order to focus activities in the Expert Centre for current need in the concrete industry, a reference group of industrial partners was established. The group includes major building owners in Denmark (The Danish Road Authority, Banedanmark, Femern A/S and Metroselskabet I/S), contractors (E. Pihl & Søn, MT Højgaard), consulting engineers (Grøntmij | Carl Bro, Rambøll Danmark A/S, NIRAS A/S and COWI A/S), an educational service institute (DKBI) and a cement producing company (Aalborg

Portland). Input from the reference group has been used for the refinement of the activities.

Activities

Specific topics were initially identified by the Expert Centre as the main areas of interest for the project:

- Materials - understanding of chloride binding mechanisms and the study of the long-term durability of concrete structures in marine environments.
- Structures - influence of micro defects on durability, improved knowledge about reinforcement corrosion and resulting crack formation.
- Execution - effect of critical construction details, rheology and casting.
- Service life modeling - development of numerical tools for prediction of chloride ingress, and the initiation and propagation of corrosion, forming a basic setup for a service life prediction tool.

Based on the above, a draft gross list of ideas for possible activities was generated and sent to the reference group for view exchanging. The list served as background for comments and discussions during a kick-off seminar, held in January 2011.

The activities chosen for the investigation in the project are shown in the following illustration (Figure 1) with blue oval marking.

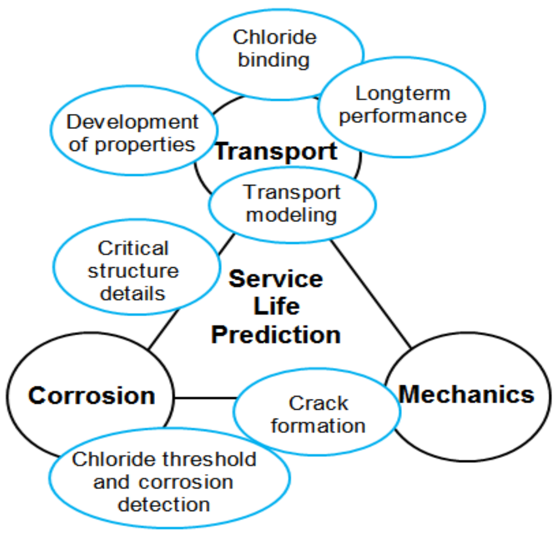

Figure 1: Schematic illustration of the activities undertaken in the project (blue oval marking), in relation to the basic components in a service life model.

The project is expected to enable valuable input to practical guidelines within all the defined areas of interest, through fundamental understanding of relevant mechanisms. Furthermore, the activities shall set a platform for the future development of a model for the service life prediction of reinforced concrete structures in marine environment and subjected to de-icing salts.

Chloride binding

It is generally agreed that when chlorides ingress into concrete, part of these become fixed to the cement paste hydrates and are therefore not available for further ingress into the concrete.

This process is generally referred to as chloride binding, and quantified by the so-called chloride binding isotherms (see Figure 2), where the equilibrium between bound chloride in the cement paste and the exposure solution is determined for increasing chloride concentrations.

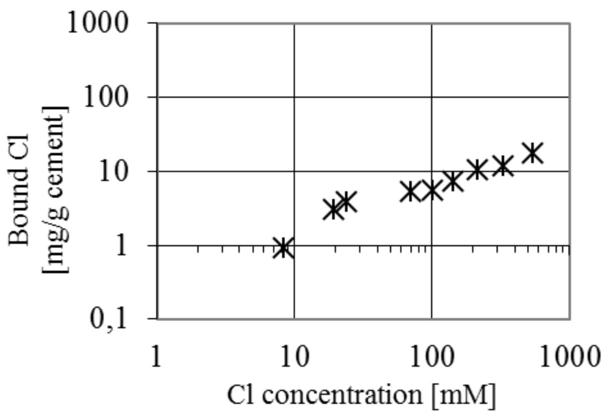

Figure 2: Example of chloride binding isotherm for an OPC cement paste with high w/c.

An existing tool for the prediction of chloride binding and pore solution chemistry in concrete is currently being expanded to include a much wider composition of binders, such as high contents of fly ash and slag. The tool shows very fine correlation with data from the literature, but will be further validated against ongoing experimental studies of chloride binding on cement pastes with significant variations in the chemical composition.

The main goal is to be able to predict the performance, in terms of chloride binding, of concretes with varying binder compositions, based on the mix design and the chemical composition of the binder.

The ingress of aggressive ions in “real” concrete blocks exposed to seawater for 6 months in Rødby Harbour has been studied by means of EDX analysis and microscopy to understand and rank the relevant chemical and physical processes that result from exposure to marine environment.

So far, the study has revealed processes unknown to date, on the reactions occurring at the surface-near region of concrete exposed to combined sulfate and chloride attack, which are expected to bring valuable information to existing models for service life prediction.

In 2012, these studies will be repeated. The total exposure time will then be 2 years.

Long term performance

Representative "old" infrastructure constructions in Danish marine environment have been selected for the study of the ingress of aggressive ions and the understanding of chloride binding in concrete exposed to aggressive environment for decades. One of the purposes by doing so is to validate the interpretation of short term observations for the predictions of long term performance.
We are presently planning the investigations on concrete samples from the "Gl. Lillebæltsbro" Bridge, the Great Belt Bridge, the Øresund Belt Bridge and Vejlefjord Bridge. Furthermore, we are presently in dialogue with major building owners to obtain concrete samples from further 2-3 larger infrastructure concrete projects in marine environment.

Transport modeling

It is the intention to be able to predict the performance of a concrete in a certain marine environment with respect to chloride ingress, based on the binder composition and the mix design of the concrete, without having to carry out extensive and time-consuming calibration experiments. The chloride ingress profile over time will thereby allow for the evaluation of the time for chloride induced corrosion initiation. This is schematized in Figure 3.

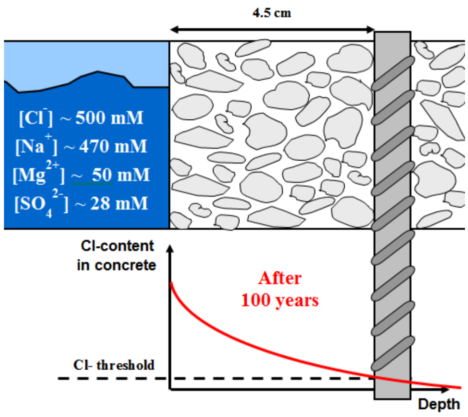

Figure 3: Schematic prediction of the time to initiation of chloride induced corrosion.

Mads Mønster Jensen has initiated his Ph.D. project at DTU Byg, funded by the Expert Centre, on the development of a coupled transport and chemical model for durability predictions of cement based materials. The project is co-supervised by DTI.

Chloride threshold and corrosion detection

Little agreement is found in the literature about the triggering chloride threshold value for reinforcement corrosion, and even less among parameters influencing the propagation of the corrosion process. As illustrated in Figure 3, the chloride threshold value is by itself a decisive parameter to evaluate the time to initiation of chloride-induced reinforcement corrosion.

The Expert Centre is a member of the RILEM TG 253 CTC group, working with the development of a standardized test method for determining threshold values for chloride induced reinforcement corrosion.
Experiments have been initiated to test the influence of selected parameters that are presently under discussion in the RILEM Group, such as pretreatment of reinforcement bars, potentiostatic vs. free potential conditions, and concrete cover.

The chloride binding tool described earlier is able to predict the performance of concretes with different binder compositions with respect to initiation of chloride induced corrosion by means of pure electrochemical considerations. Crushed, mature concrete samples have been exposed to increasing chloride concentrations to validate the predictions of the model.

Crack formation

Anna Emilie Thybo has initiated her Ph.D. project at DTU Byg funded by the Expert Centre on the development of mechanical properties in concrete following the propagation of reinforcement corrosion. The project is co-supervised by DTI.

A Post Doc, Bradley Justin Pease, also funded by the Expert Centre is presently working with the development of a test method for the detection and study of reinforcement corrosion by means of X-ray techniques. Furthermore, corrosion propagation is experimentally studied in regions near cracks in concrete exposed to seawater.

Service life simulation tool

Alexander Michel is currently carrying out his Ph.D. project partly funded by the Danish Agency for Science, Technology and Innovation and Femern Bælt A/S and integrated in the Expert Center through DTU Byg co-founding. The project deals with integrating transport models, electro-chemical models and fracture mechanical models into one service life simulation tool capable of dealing with both corrosion initiation and the corrosion propagation phase. The individual models developed in the Expert Centre will be integrated in this integrated framework.

Critical structure details

As self-compacting concrete (SCC) finds increased application in the construction industry, the study of critical structure details was carried out for both conventional concrete and SCC. All activities have been completed, and the major findings are:

- Poker vibrators: As long as the guidelines given by HETEK (Danish Road Directorate´s research programme on High Performance Concrete – The Contractor´s Technology) are followed, no measurable decrease in concrete quality can be observed.

- Cold casting joints: The chloride migration coefficient in cold joints is up to twice as high as that of the concrete, even when the aggregates have been exposed by 5-10 mm by sandblasting prior to the subsequent casting.

- Warm casting joints: No increased chloride migration coefficient has been observed in joints between to SCC casting for intermediate times up to 2 hours.

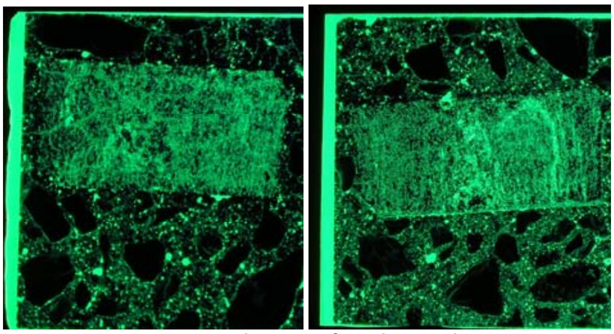

Figure 4: Porosity in the interfacial zone between spacer and concrete for (left) pre-dried and (right) wet spacer.

- Concrete spacers: Increased porosity, and thereby increased chloride ingress, will always be observed in the interfacial zone between a spacer and the surrounding concrete (see Figure 4). This effect is significantly reduced when using surface-dried spacers.

Within all the subjects studied, SCC with water content variations of less than ± 5 l/m^3 concrete was found to show similar performance than traditional concrete in terms of critical structure details.

Development of properties

The effect of curing regime on strength properties has been widely studied through decades and found well described by the maturity function. Furthermore, these studies have become outdated following the development in concrete technology. This activity will focus on the effect of curing conditions on transport properties, mainly chloride ingress, of modern concretes. Activities will be initiated in autumn 2011.

Cooperation between DTU and DTI

The Expert Centre is based on the close cooperation and exchange of knowledge and equipment between DTI and DTU. Already implemented cooperation activities include:

- Quarterly steering meetings
- Biannual status meetings
- Supervisory meetings for the M.Sc. and Ph. D. projects
- Equipment sharing, as e.g. SEM/EDX and X-ray
- Co-writing of journal and conference papers

Coming up soon

Take the time to visit us at our exhibition stand at Dansk Betondag 2011.

The next meeting with the reference group takes place 14/10/2011.

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