2012
ICDC
INTERNATIONAL CONGRESS on DURABILITY of CONCRETE

# DANISH EXPERT CENTER FOR INFRASTRUCTURE CONSTRUCTIONS

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## ABSTRACT

A Danish Expert Center for infrastructure constructions was established in 2010 setting a platform for cooperation between the Danish Technological Institute and the Technical University of Denmark for the study of durability of reinforced concrete in aggressive environments. The cooperation runs over a three year period, with primary focus on the degradation processes in concrete resulting from exposure to chlorides, either from marine or de-icing salts environments. The ambition is to continue the cooperation based on funding from EU´s 7th and 8th framework programme.

The paper outlines the approach adopted in the Expert Center and the activities initiated, providing background motivation and some ideas for overcoming different unresolved issues. However, results so far, mainly concerning the effect on durability of selected critical structure details, such as vibration, joints and concrete spacers, are presented.

Self-Compacting Concrete has been studied against conventional slump concrete with respect to critical structure details and found to show similar performance on all studied subjects, within practically applicable ranges of water dosage (± 5 $l/m^3$).

**Key-words:** Durability, Sea water ingress, Chloride binding, Corrosion, Long term performance, Service life prediction

## INTRODUCTION

The Danish Expert Center 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 technical centers in Denmark with respect to durability and service life of reinforced concrete structures in aggressive and extra aggressive environments, such as tunnels, bridges and off shore windmill structures. The aim is to combine and utilize complementary competences and laboratory facilities, and to carry out coordinated and common PhD, post-doc and master projects.

Denmark as well as other European countries faces enormous future challenges with major infrastructural projects, and maintenance and repair of the existing worn-down structures. It is estimated that the annual expenses in EU related to the physical infrastructure is around 0.3 trillion euro, corresponding to 2-3 % of the GNP [1].

The ambition is to continue the cooperation based on funding from EU´s 7th and 8th framework programme. The Expert Center will seek influence from an active participation in official EU lobby networks related to the infrastructure (current working title: Refine).

## Activities in the Danish Expert Center

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

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

1. Materials - understanding of chloride binding mechanisms and the study of the long-term durability of concrete structures in marine environments, rate of ingress in different concrete types, threshold value for chloride induced reinforcement corrosion
2. Structures - influence of micro defects on durability, improved knowledge about reinforcement corrosion and resulting crack formation following the propagation of corrosion
3. Execution - effect of critical construction details, SCC rheology and casting methodology
4. 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

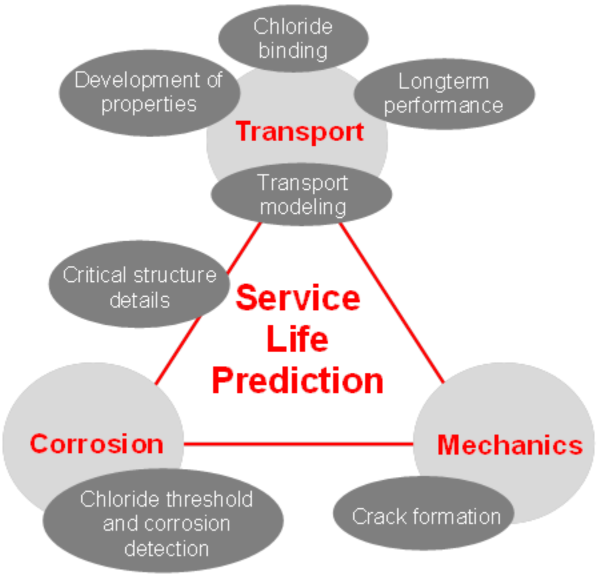

*Figure 1 – Schematic illustration of the activities undertaken by the Expert Center, in relation to the basic components in a service life prediction model*

Based on this, a list of activities was defined and planned (see Figure 1).

The project is expected to bring 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.

The present paper describes the content, motivation and status for each of the activities undertaken by the Expert Center.

### 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.

## SERVICE LIFE

In Denmark, most of the major reinforced concrete structures for infrastructural purposes 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 mechanical 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 [2]: the initiation and the propagation period.

1. The initiation period 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. This is the criterion that is and has been used in specification of concrete service life.

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

The largest economic benefit though is probably obtained by prolonging the initiation period through proper concrete mix selection, smart structural design and clever choices in the execution phase.

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 (e.g. [3]). The extrapolation of short term observations of chloride ingress from accelerated testing can be obtained by empirical, physically based or probabilistic approaches, according to [4]. “Empirical” models are mainly based on the error-function solution to Fick’s 2. law of diffusion, which is restricted to diffusion in porous media where, among other limitations, no interaction between species in solution and hydrates in the cement paste or between ions in solution occur, and the environmental loading is constant. A so-called apparent diffusion coefficient measured at a certain time of exposure is therefore applied to predict the ingress after e.g. 100 years. Interaction of species with the hydrates of the cement paste, environmental properties, temperature, etc., is accounted for by empirical factorisation. The “physically based” models use finite element modelling techniques, where the transport of chlorides is regarded in multi-component solutions, as is the case for concrete pore solution, to account for interaction between the different species in solution (e.g. [4]) and the hydrates of the cement paste. Sometimes the chemical activity of the ions in solution is included [5]. The “probabilistic” models are extensions of the “empirical” models that account for the many sources of error arising from inhomogeneity of the concrete, varying environmental load, production defects, etc., by means of statistical treatment of a large amount of data (see e.g. [6]).

Common to most, if not all service life prediction models is that they cannot accurately predict the performance of a concrete in e.g. a marine environment without previously carrying out extensive measurements [4] to calibrate e.g. chloride binding, chloride concentration at the surface of the concrete, capillary porosity of the concrete, etc. Some authors (e.g. [7]) have even stated that service life prediction of High Performance Concrete is an impossible task and recommend focusing on the development of guidelines and rules for material selection and casting, etc, instead.

## CHLORIDE BINDING

### Performance of different concrete binders in terms of 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 and for initiation of corrosion. This process is generally referred to as chloride binding, and quantified by the so-called chloride binding isotherms, where the equilibrium between bound chloride in the cement paste and the exposure solution is determined for increasing sodium chloride concentrations. In some cases, calcium chloride is used instead. However, many conflicting conclusions are found in the literature suggesting the need for a better understanding of the basic mechanisms.

The chloride binding in cement pastes has in several studies (as e.g. [8, 9]) been concluded to be highly dependent on the alkali content, amongst many other parameters. This, combined with the fact that the rate of ingress of alkalis in concrete exposed to seawater or de-icing salts is several orders of magnitude lower than that of chloride [10], suggests that the use of traditional sodium chloride binding isotherms for service life prediction is erroneous.

To overcome the above, thermodynamic models for the phase equilibria in hydrated Portland cement binder systems, which are presently emerging throughout the literature, could be applied.

In order to illustrate their possible application, the model described and verified in [11, 12] is adopted in the following. In Figure 2, predictions of both sodium chloride and calcium chloride binding isotherms of a w/c 0.40 ordinary Portland cement paste are shown. The simulations are carried out for two cases: a cement paste submerged in an exposure solution (with a ratio of exp. sol. to paste at 1.5) corresponding to typical conditions found in the literature for determining chloride binding isotherms (left-hand side), and without exposure solution corresponding to that inside real concrete exposed to chloride, where dilution is minimized (right-hand side).

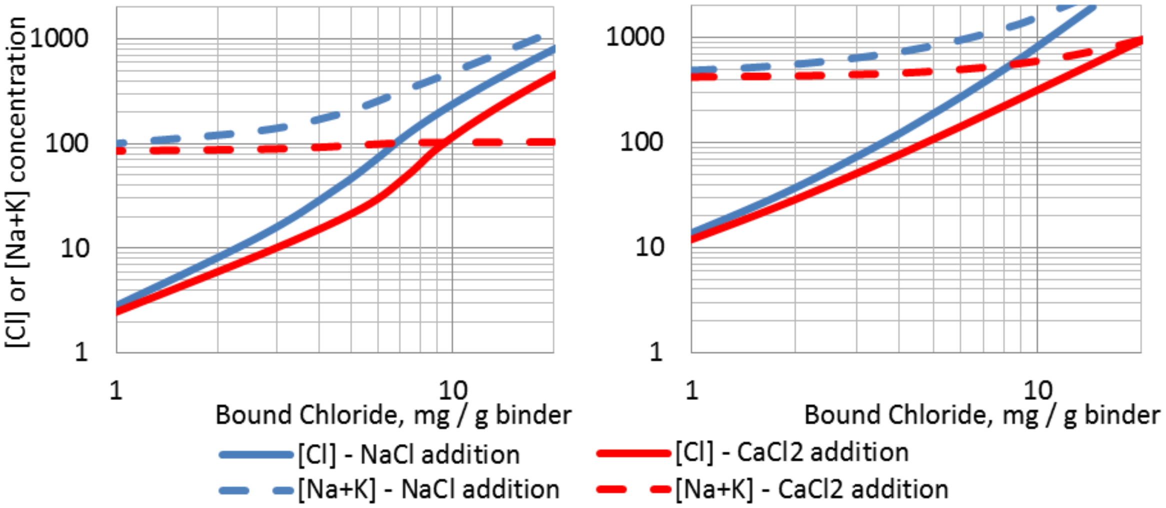

*Figure 2: Chloride binding isotherms in ordinary Portland cement paste at water-to-cement ratio 0.40 with varying chloride source (NaCl and CaCl$_2$) and varying amounts of exposure solution: solution to paste ratio at 1.5 (left-hand side) and no exposure solution (right-hand side).*

The chloride binding isotherm of a cement paste is expected to vary remarkably depending on the chloride source and the ratio of exposure solution to cement paste. This raises the question of which chloride binding isotherm should be used in service life prediction evaluations. Modeling techniques can be a useful tool for “translating” traditional chloride binding isotherms and suitable for accounting for the specific environment applicable for the regarded concrete structure.

The application of the model above is limited to pure Portland cement pastes with or without relatively small additions of supplementary cementitious materials. To expand the application of that model, crushed cement paste samples are presently being exposed to increasing chloride concentrations to determine the chloride binding isotherms. The binder compositions of these are shown in Table 1.

*Table 1 – Chloride binding experiments (water-to-powder ratio at 0.40)*

| Binder compositions | Exposure Solutions |
|---|---|
| CEM I 42,5N (HS/EA/<2) cement (SRPC)<br>CEM I 52,5N (MS/LA/<2) cement (OPC)<br>CEM III/B 42,5N slagcement<br>96% SRPC + 4% Silica Fume<br>75% SRPC + 25% Fly Ash<br>30% OPC + 70% Blastfurnace Slag | 0.05, 0.1, 0.5 and 1.0 mole/liter NaCl |

The main goal of this activity 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, without having to carry out extensive and time consuming investigations.

## Seawater ingress into concrete

The chemical and physical (e.g. formation of cracks, increased porosity, etc.) properties of the cement paste in concrete exposed to seawater are altered through time, following simultaneous processes of chloride ingress, leaching, sulfate attack, brucite formation, carbonation, etc.

Therefore, the ingress of aggressive ions in “real” concrete blocks from Fehmarn Belt Fixed Link exposure site in Rødby Harbour is followed over time by means of EDX analysis and optical microscopy. The aim is to understand and rank the relevant chemical and physical processes that result from exposure to marine environment, and the differences resulting from varying binder compositions.

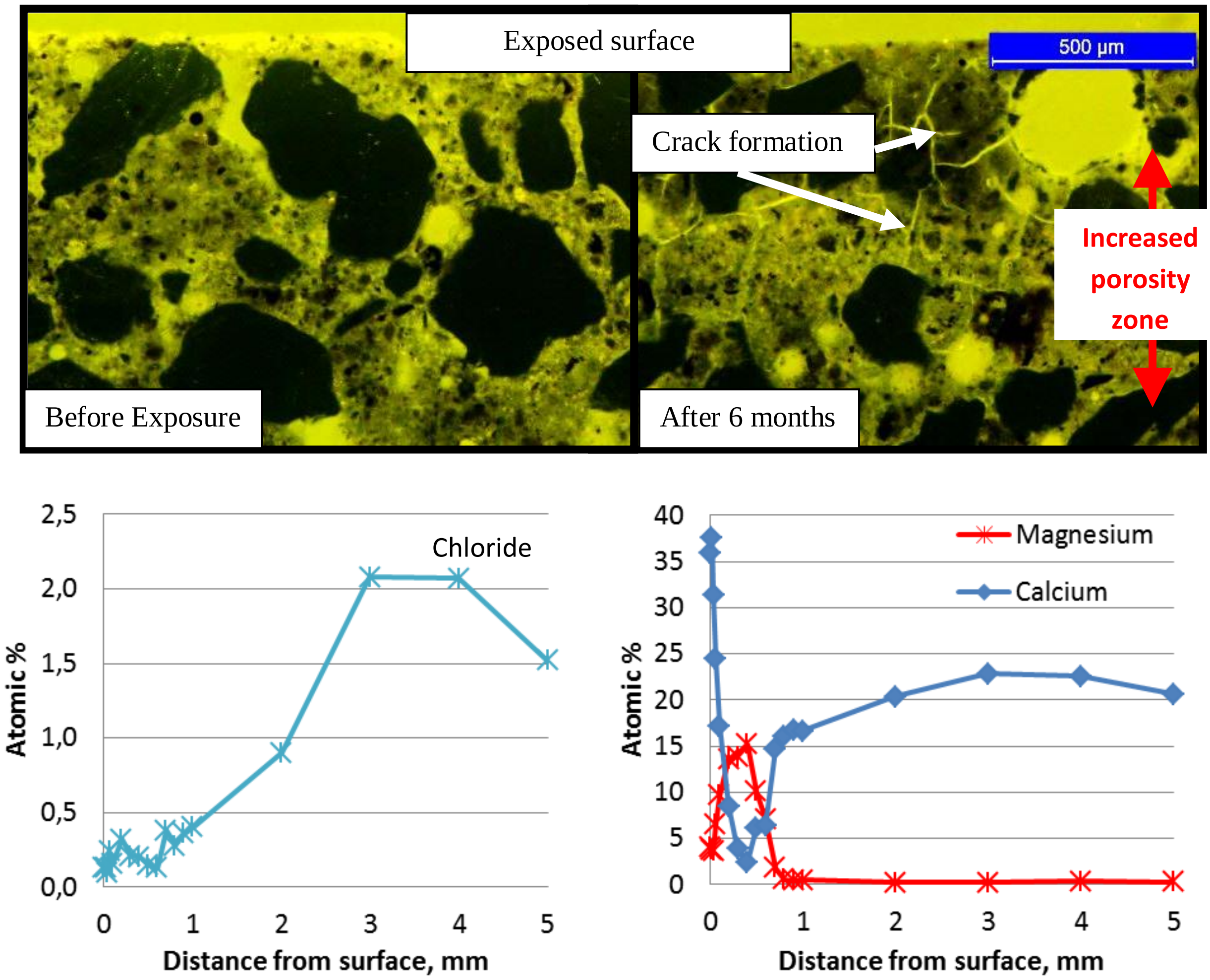

*Figure 3 – Results from some of the SEM-EDX measurements carried out on CEM I 42,5N (HS/LA/<2) with 12% Fly Ash and 4 % Silica Fume, after 6 months of exposure to sea water in Rødby Harbour*

Figure 3 shows some of the measurements carried out on a water-to-cement ratio 0.40 concrete of a CEM I 42,5N (HS/LA/<2) cement with 12% Fly Ash and 4 % Silica Fume, exposed 6 months to seawater in Rødby Harbour. After 6 months, an interstitial zone of increased porosity and crack formation is observed at a few millimeters from the exposure surface. This high porosity zone is coincident with a high content of brucite and low content of calcium. At the surface near zone of the concrete, no chloride binding minerals seem to be stable.

The very short exposure time of the concrete in Figure 3 makes the observations above non-conclusive. However, the measurements are planned to be repeated at 2 and 5 years of exposure. The development of the observed mechanisms over time will allow for the deduction of practical conclusions on the performance of each binder type in seawater environment.

## LONG TERM PERFORMANCE

Representative "old" infrastructure constructions in Danish marine environment have been selected for the study of the long term performance of different concretes exposed to aggressive environment for several decades. Each structure selected has a binder composition similar to one of the concretes currently placed at the Fehmarn Belt Fixed Link exposure site, i.e. represent how the microstructure can be expected to appear in 15+ years. Initially, the studies are focused on the degradation mechanisms occurring just below sea level, where the exposure conditions can be more accurately defined than in the more aggressive splash zone.

It is the intention to identify and quantify the predominant processes affecting the service life of a reinforced concrete structure, and to validate the interpretation of short term observations for the predictions of long term performance.

The Expert Centre is currently in dialogue with relevant building owners to obtain samples and carry out investigations on the concrete structures listed in Table 2.

*Table 2 – Bridges selected for the long term study of chloride ingress*

| Bridge | Exposed since | Binder composition |
|---|---|---|
| Old "Little Belt" Bridge | 1929-1935 | Pure Portland cement |
| Great Belt Bridge | 1987-1998 | Sulphate resisting PC + Fly Ash + Silica Fume |
| Øresund Bridge | 1993-2000 | Sulphate resisting PC + Silica Fume |
| Vejlefjord Bridge | 1975-1980 | Slagcement |
| Farø Bridges | 1980-1985 | Sulphate resisting Portland cement + Fly Ash |
| Alssund Bridge | 1978-1981 | Pure sulphate resisting Portland cement |

## 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. In [13], a summary of 13 studies on chloride content required to initiate the corrosion of steel in concrete is presented, reporting values ranging from 0.17 to 2.5 weight% by mass of binder in the concrete or mortar. The highest values are usually determined in concretes with poor oxygen availability at the steel-concrete interface (concrete with low water-to-cement ratio, submerged exposure environment, etc.).

It appears that two main parameters influence the initiation of corrosion in reinforced concrete structures exposed to chloride [14]: the ratio of chloride to hydroxyl ions concentration in the pore solution and the electrochemical potential through the concrete cover. These parameters are of course highly dependent on e.g. concrete quality, binder composition, water-to-cement ratio, oxygen permeability, degree of water saturation, temperature, etc.

The DuraCrete model for Durability Design of Concrete Structures [15] suggests the use of different chloride threshold values, depending mainly on the water-to-binder ratio and the exposure environment. The characteristic values for critical chloride concentration in concrete permanently submerged in seawater ranks from 1.6 to 2.3 weight-% relative to the binder, whilst 0.50-0.90 weight-% applies for tidal and splash zone exposed concrete.

The chloride threshold value is by itself one of the most decisive parameters for the evaluation of the service life of a reinforced concrete structure. A scatter of an order of magnitude, as that observed in [13], in the chloride threshold values, may result in uncertain service life predictions varying more than several decades.

## A test for determining the chloride threshold value in concrete – practical approach

The Expert Center is member of the Rilem TC 235 CTC group, working with the development of a standardized test method for determining threshold values for chloride induced reinforcement corrosion in concrete.

Experiments are therefore designed according to the discussions and suggestions in the Rilem task group. Initially, tests have been initiated to study the effect of the concrete cover depth (5 and 15 mm), the applied potential (potentiostatic at 100 and -150 mV Ag/AgCl following an approach in principle similar to that in [16] vs. free potential conditions) and pre-treatment of reinforcement bars (pre-rusted vs. pretreatment in citric acid). Figure 4 illustrates the experimental setup.

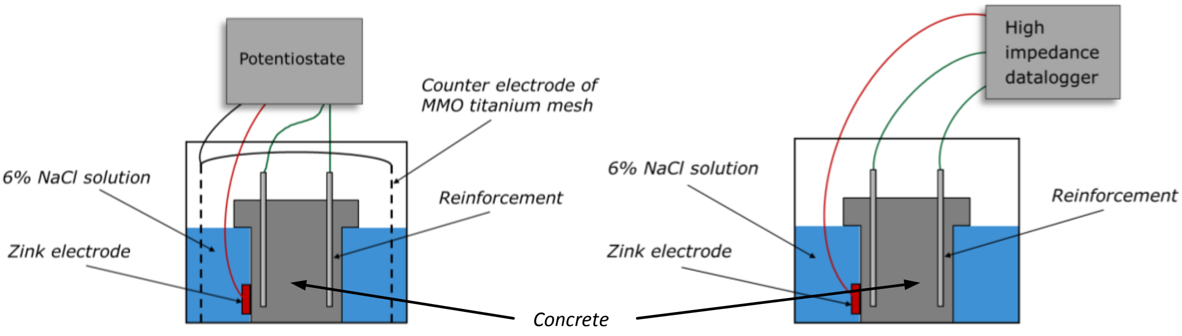

*Figure 4 – Experimental setup for the determination of chloride threshold values in concrete: potentiostatic exposure (left-side) and free potential (right-side)*

## A test for determining the chloride threshold value in concrete – theoretic approach

As described earlier, there is a general agreement that one of the most important parameters for the initiation of reinforcement corrosion in sea water exposed concrete is the ratio of chloride to hydroxyl ions in the pore solution. A typical value assumed for that parameter is approx. 0.50-0.60. A recent approach has been proposed in [17], where the alkali content in the binder is used to estimate the concentration of hydroxyl ions in the pore solution, followed by the estimation of the chloride concentration by multiplication of the ratio mentioned above. The chloride threshold value is thereafter deduced by empirically determined equations describing the chloride binding isotherms of the examined binder.

The chloride binding tool applied in Figure 2 is, according to the reasoning above, 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. The ratio of chloride to hydroxyl ions in the pore solution for increasing chloride content in the cement paste described in Figure 2, is shown in Figure 5.

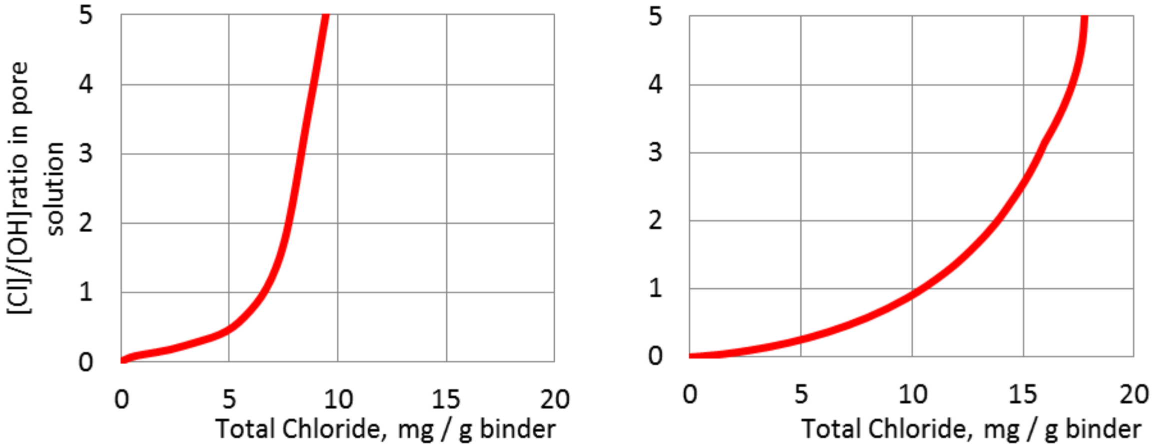

*Figure 5: Chloride to hydroxyl ions ratio in the pore solution of the cement paste in Figure 2, for increasing total content of chloride (source $CaCl_2$), with exposure to paste ratio at 1.5 (left-hand side) and without exposure solution (right-hand side).*

It is observed that the experimental setup may have a dramatic impact on the measured values. According to the criterion above for threshold values defined at [Cl]/[OH] ~0.50-0.60, the chloride threshold value in this cement paste, in terms of total chloride content, would be approx. 7 mg chloride per gram binder (i.e. 0.7% by weight of binder). This value is within the experimentally determined range mentioned earlier, but significantly lower than the value recommended in the DuraCrete model.

This approach is currently being further examined. 6 samples of approx. 1.0 kg each of a total of 5 mature concretes (see Table 3) from the Femern exposure site in Rødby Harbour have been drilled and crushed to maximum particle size of 4 mm, and exposed in the laboratory to 350 ml solutions with increasing concentrations of chlorides at a constant alkali concentration level. The binder composition of the concretes, cover a wide range of supplementary additions. The solutions will be examined for chloride, alkali and hydroxyl ion concentration after 4 months of exposure.

### Corrosion detection

The Expert Centre is funding a Post Doc project on 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.

## CRITICAL STRUCTURE DETAILS

The main focus of concrete durability studies has generally been placed on the improvement of the properties of concrete as a material with a certain average composition. However, to further improve long term durability understanding, attention also needs to be paid to minimizing casting defects.

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.

The test program was divided into the following four areas:

1. Different types of casting joints
    a. Cold joints (SCC vs. conventional slump concrete)
    b. SCC ”distinct” layer casting (warm joint at 1 and 2 hours)
2. Reinforcement spacers – influence of the interface zone between spacer and concrete
3. Vibration – effect of poker vibrator track in the concrete
4. SCC mixed with ± 5 $l/m^3$ of water – influence on rheology and the potential corresponding casting difficulties/defects

For each area, 1x1x0.2 m concrete slabs were cast and samples were drilled/cut for visual/petrographic evaluation, and chloride migration (NT Build 492) and frost resistance at comparable maturity. A 3-powder (low alkali cement, fly ash and microsilica) concrete with w/c 0.40 was used for all investigations.

## Different types of casting joints

Four different casting joints were investigated:

1. Traditional slump concrete and SCC with 5 days old joints (cold joint)
2. SCC with 1 and 2 hours delay between castings (warm joint)

Cold joints were generated by filling the formwork halfway. After 5 days, the top surface was sandblasted to expose 5-10 mm aggregate, followed by casting of a new concrete layer. Warm joints were generated by direct casting of the second layer after 1 and 2 hours, without prior pretreatment of the surface.

The petrographic analysis showed that only cold joints show noticeable increased porosity in the interface zone.

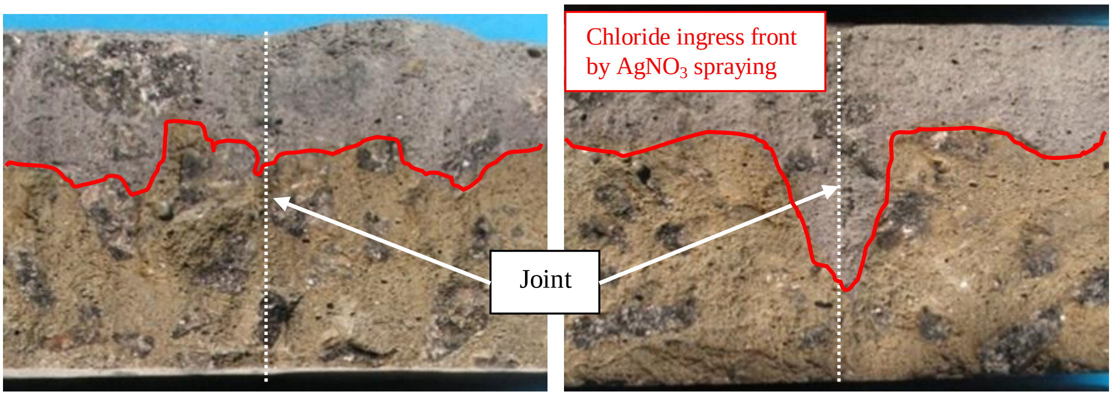

*Figure 6: Chloride penetration by $AgNO_3$ spraying according to NT BUILD 492. Inner sample of cold joint (left-hand side) and surface sample of cold joint (right-hand side)*

Chloride migration analysis was performed on cylinders drilled perpendicular to the joints. The cylinders were cut into 5 cm thick slices and both surface and inner samples were analyzed. For the cold joints, some surface samples showed an increased penetration of chlorides in the joint,(see Figure 6) compared to that in the surrounding concrete (chloride migration coefficient of $17 \times 10^{-12}$ $m^2/s$ in the joint compared to $7 \times 10^{-12}$ $m^2/s$ in the concrete). However, no difference between joint and concrete was observed for the inner samples.

No difference was observed in terms of chloride migration in warm joints, for neither surface nor inner samples.

The bond in the joints was tested by tensile strength measurements, using cylinders drilled through the joint. Only one out of 4 cylinders from cold joints showed fracture in the joint. All other cylinders (both cold and warm joints) showed fracture in the concrete surrounding the joint.

### Reinforcement spacers

Three types of reinforcement spacers were investigated:

1. Concrete (butterfly shape), wet/dry
2. Fiber cement (butterfly shape), wet/dry
3. Plastic (round lamellar)

Cylinders were drilled around the different spacers and used for visual and petrographic evaluation, and chloride migration analysis.

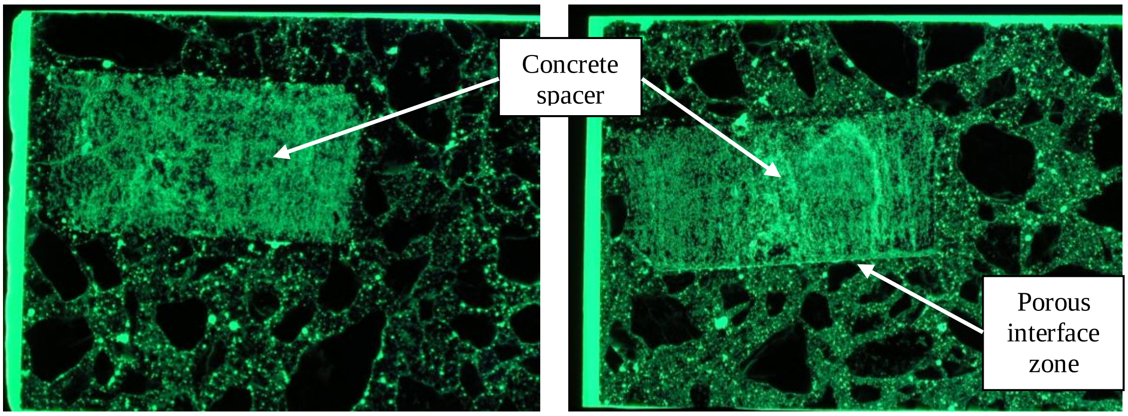

*Figure 7: Porosity in the interfacial zone between spacer and concrete for (left) pre-dried and (right) wet spacer.*

For both traditional slump concrete and SCC, a porous zone was observed on the bottom side of the spacer, which becomes particularly pronounced when casting against wet spacers (see Figure 7).

The chloride migration tests showed increased penetration in the porous zone on the bottom side of the spacer. Furthermore, all examined spacers showed a remarkably poorer quality than the casted concrete in terms of chloride ingress.

### Vibration

The effect of poker vibrator tracks was studied by casting a slump concrete in 3 layers and only vibrating in the center of the formwork. The vibration was carried out according to the HETEK (Danish Road Directorate´s research program on High Performance Concrete – The Contractor´s Technology) guidelines.

Cylinders for air void analysis and determination of frost resistance were drilled in 3 positions (1 centered directly in the vibrator track and 2 centered respectively 18 and 36 cm away from this).
The air void analysis indicates that the air content in the vibrator track is lowered, and the specific surface is higher, compared to the 2 other positions. This indicates that larger air voids are removed as a result of the vibration.

The frost resistance tests revealed similar performance for all three samples, showing “very good frost resistance” (scaling below 0.1 kg/m$^2$ at 56 cycles).

## SCC - effect of ± 5 l/m$^3$ of water variations

The influence of variations in water dosage of max. 5 l/m$^3$ on SCC fresh and hardened properties was studied, corresponding to realistic limits for a full-scale production.

The rheological properties were measured using the 4C-Rheometer, and cylinders were cast for determination of compressive strength at 28 days and chloride migration.

The induced variations affect influence both fresh and hardened concrete properties. As expected, the slump flow increases and the viscosity decreases following increased additions of water. Parallel to that, the compressive strength is reduced and the chloride migration coefficient increases.

*Table 4 – Air content, compressive strength and migration diffusion coefficient according to NT BUILD 492 for SCC with water content variations of* ± 5 l/m$^3$

| Concrete type | w/c | Air content [%] | Compressive strength [MPa]* | $D_{nssm}$ [m$^2$/s] |
|---|---|---|---|---|
| Reference | 0.401 | 3.2 | 60.7 | 7.4 x 10$^{-12}$ |
| ÷ 5 l/m$^3$ | 0.388 | 4.8 | 63.5 | 6.3 x 10$^{-12}$ |
| + 5 l/m$^3$ | 0.412 | 3.5 | 56.0 | 8.0 x 10$^{-12}$ |

*Normalized to 4% air content by assuming 4% strength reduction by 1% decrease in air content

However, SCC with water content variations of less than ± 5 l/m3 concrete was found to show similar performance than traditional concrete in terms of critical structure details.

## DEVELOPMENT OF PROPERTIES

In 1977, a function able to compute a maturity index from the recorded temperature history of a concrete, commonly named the Maturity function, was proposed [18]. This function was based on the Arrhenius equation, often used to describe the effect of temperature on rate of chemical reaction. This function allows for conversion of the actual age of the concrete to an equivalent age (Maturity) at a reference temperature (20$^o$C).

The effect of curing strategy on strength properties has been widely studied through decades and found well described by the maturity function. However, the underlying data for the predictions have become outdated as a consequence of the advances in concrete technology.

Furthermore, the construction of concrete structures normally involves exposure to the aggressive environment at a relatively low concrete maturity. The effect of this early exposure has not been covered to a level in the literature that allows for practical decision making guidelines during drafting and planning of concrete activities.

This activity will focus on the quantification of the effect of curing conditions on strength development and transport properties, mainly chloride ingress, of modern infrastructure concretes, for a wide range of temperatures. The activities will be initiated in autumn 2011.

## SERVICE LIFE PREDICTION

A Ph.D. project partly funded by the Danish Ministry of Science, Technology and Innovation and Fehmarn Belt Fixed Link 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. Two models are currently being developed in the Expert Centre, i.e. a transport model and a crack formation model for the propagation of corrosion, which will ultimately be integrated in this framework.

### Transport model

It is the intention to be able to predict the performance of a concrete in a certain marine or de-icing salts 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, and that of other relevant ions, over time, and the interaction of these with the cement paste minerals, will thereby allow for the evaluation of the time for chloride induced corrosion initiation.

A coupled transport and chemical model for durability predictions of cement based materials is being developed by a Ph.D. student at DTU Byg. The project is co-supervised by the Danish Technological Institute.

### Crack formation model

A Ph.D. project at DTU Byg on the development of mechanical properties in concrete following the propagation of reinforcement corrosion. The project is co-supervised by the Danish Technological Institute.

Both Ph.D. projects have been initiated in march 2011.

## CONCLUSIONS

A platform for cooperation between the Danish Technological Institute and the Technical University of Denmark has been established with respect to durability and service life of reinforced concrete structures in aggressive and extra aggressive environments, under the name Expert Centre for Infrastructure Constructions. The cooperation agreement runs until the end of 2012, but is expected to be prolonged through funding by EU´s 7th and 8th framework programme.

The paper outlines the approach adopted by the Expert Center, presenting the undertaken activities, as well as the motivation and status of these. Results from the different activities will be published as the project advances. However, the results to date have been presented in the paper, mainly concerning critical structure details, and the major findings include:

1. 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 when compacting by use of poker vibrators.
2. 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.
3. No increased chloride migration coefficient has been observed in joints between two SCC casting for intermediate times up to 2 hours.
4. Increased porosity, and thereby increased chloride ingress, will always be observed in the interfacial zone between a spacer and the surrounding concrete. This effect is significantly reduced when using surface-dried spacers.

SCC with water content variations applicable for full scale production (less than ± 5 $l/m^3$ concrete) was found to show similar performance than traditional concrete in terms of critical structure details.

## REFERENCES

1. Building Up Infrastructure Networks of a Sustainable Europe, Initiative of European Construction, Technology Platform, refine, www.ectp.org.
2. Tuutti, K. Corrosion of Steel in Concrete. Swedish Cement and Concrete Research Institute, Stockhom. Report No. CBI Research FO 4:82, 1982.
3. HETEK report no. 83, A system for prediction of chloride ingress into concrete, Theoretical background. Nilson, L.-O., Sandberg, P., Poulsen, E., Tang, L., Andersen, A. and Frederiksen, J.M. The Danish Road Directorate, 1997.
4. Truc, O., Prediction of chloride penetration into saturated concrete – Multi-species approach, Doctoral Thesis, publication P-00:4, Department of Building Materials, Chalmers University of Technology, Göteborg, Sweden, 2000.
5. Samson, E., Marchand, J. and Maltais, Y., Modelling Ionic Diffusion Mechanisms in Saturated Cement-Based Materials-An Overview. In: Ion and mass transport in cement-based materials, pp. 97-112, Edited by: Hooton, R.D., Thomas, M.D.A., Marchand, J. and Beaudoin, J.J. Materials Science of Concrete, Special volume. The American Ceramic Society, United States of America, 2001.
6. Lindvall, A., Probabilistic, Performance-Based Service Life Design of Concrete Structures: Environmental Actions and Response. In: Ion and mass transport in cement-based materials, pp. 323-340, Edited by: Hooton, R.D., Thomas, M.D.A., Marchand, J. and Beaudoin, J.J. Materials Science of Concrete, Special volume. The American Ceramic Society, United States of America, 2001.
7. Palecki, S. and Setzer, M.J., Life-time prediction of high performance concrete with respect to durability (CONLIFE). Proceedings: Workshop on Durability of Exposed Concrete Containing Secondary Cementitious Materials, November 21-23 Hirtshals. Denmark, 2001.
8. Tritthart, J., Chloride Binding in Cement, Cement and Concrete Research, pp. 683-691, 1989.
9. Zibara, H., Binding of external chloride by cement pastes. Ph.D. thesis at the University of Toronto, 2001.

10. Volkwein, A., Penetration of chlorides into concrete – Phenomena and consequences. Points of view based on 20 years research and site experience with deicing salts. Proceedings of the International RILEM workshop on Chloride penetration into concrete, St-Rémy-lès-Chevreuse, France, 1995.
11. Nielsen, E.P., Herfort, D. and Geiker, M.R., Phase equilibria in hydrated Portland cement. Cement and Concrete Research 35 pp. 109-115, 2005.
12. Nielsen, E.P., Herfort, D. and Geiker, M.R., Binding of chlorides and alkalis in Portland cement systems. Cement and Concrete Research 35 pp. 117-123, 2005.
13. Glass, G. K. and Buenfeld, N.R., Chloride Threshold levels for corrosion induced deterioration of steel in concrete. Proceedings of the International RILEM Workshop on Chloride Penetration into Concrete, St-Rémy-lès-Chevreuse, France, 1995.
14. Arup, H., Determination of chloride threshold values (In Danish). Proceedings of the workshop: The service life of marine concrete structures, arranged by CEMENTA AB, 1993.
15. DuraCrete – Final Technical Report – Probabilistic Performance based Durability Design of Concrete Structures. The European Union – Brote EuRam III, Document BE95-1347/R17, 2000.
16. Nygaard, P. V. and Geiker, M. R.: A method for measuring the chloride threshold level required to initiate reinforcement corrosion in concrete. Materials and Structures 38, pp. 489-494, May 2005.
17. Fagerlund, Göran, The threshold chloride level for initiation of reinforcement corrosion in concrete – Some theoretical consideration. Report TVBM-3159, Lund Institute of Technology, 2011.
18. Freiesleben Hansen, P. and Pedersen, J. Maturity Computer for Controlled Curing and Hardening of Concrete. Nordisk Betong, 1, pp. 19-34, 1977.