CRC - durability

The CRC matrix is extremely dense and has very little capillary porosity – porosity is 1.5% with 14% of that in the capillary region. The rest is gel pores resulting in a very low permeability. Thus CRC is very resistant to ingress of chlorides or to carbonation, which means that the rebar cover used in CRC can be much smaller than what is necessary for conventional concretes.

This has been demonstrated in a number of investigations at e.g. Force Institutterne in Denmark and Instituto Eduardo Torroja in Spain, mainly in connection with the 2 international research projects **Compresit** (a EUREKA project) and **MINISTRUCT** (a Brite/EuRam project), where all tests were carried out using a matrix with 6% of steel fibres. As CRC is expected to sustain service loads higher than what can be expected for conventional concretes, the investigations also differ in some areas from the techniques used on conventional concrete.

Loaded beams in salt water

As CRC is often used in slender structures the stresses under service loads can be high, and it is of importance to determine whether chloride penetration rates are higher in heavily loaded structures than in structures under moderate loads. This has been investigated in a special testing rig, where small beams are exposed to chlorides while loaded to a specified deflection.

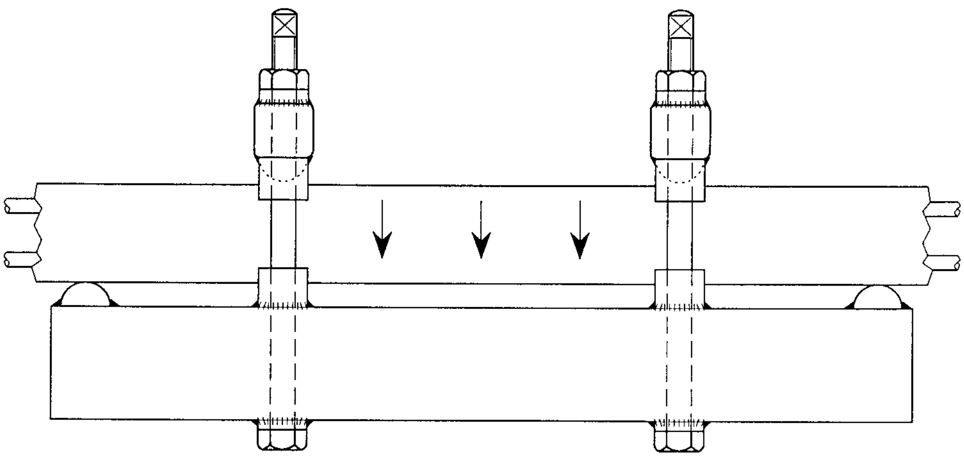

Figure 1 Test rig where reinforced beams are loaded to a specified deflection.

The results of these investigations are available in [1] and [2]. The load-deformation curve for the beams tested at Force Institutterne is shown in fig. 2. Beams were loaded to specified deflections of 0, 0.2, 1 og 2 mm and the full test rig was then exposed to a solution with 3.5% NaCl in saturated $Ca(OH)_2$ in a wetting/drying cycle. A deflection of 2 mm corresponds to a bending stress of 75 MPa and even at this load there is no increase in chloride penetration compared to a reference beam with no load. The number of microcracks is increased at higher loads, but the width of these microcracks is sufficiently small, so that there is no effect on chloride penetration. Based on these test results CRC has been used for drain covers in the Great Belt Link – with 10 mm rebar cover and a 100 year design life in a salt water environment.

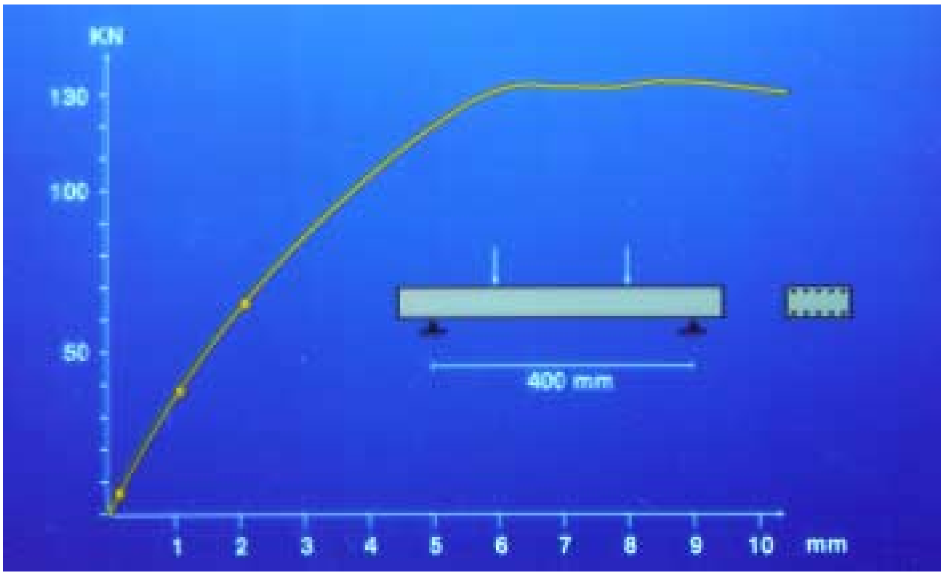

Figure 2 Load-deformation curve for 500x100x50 mm beams.

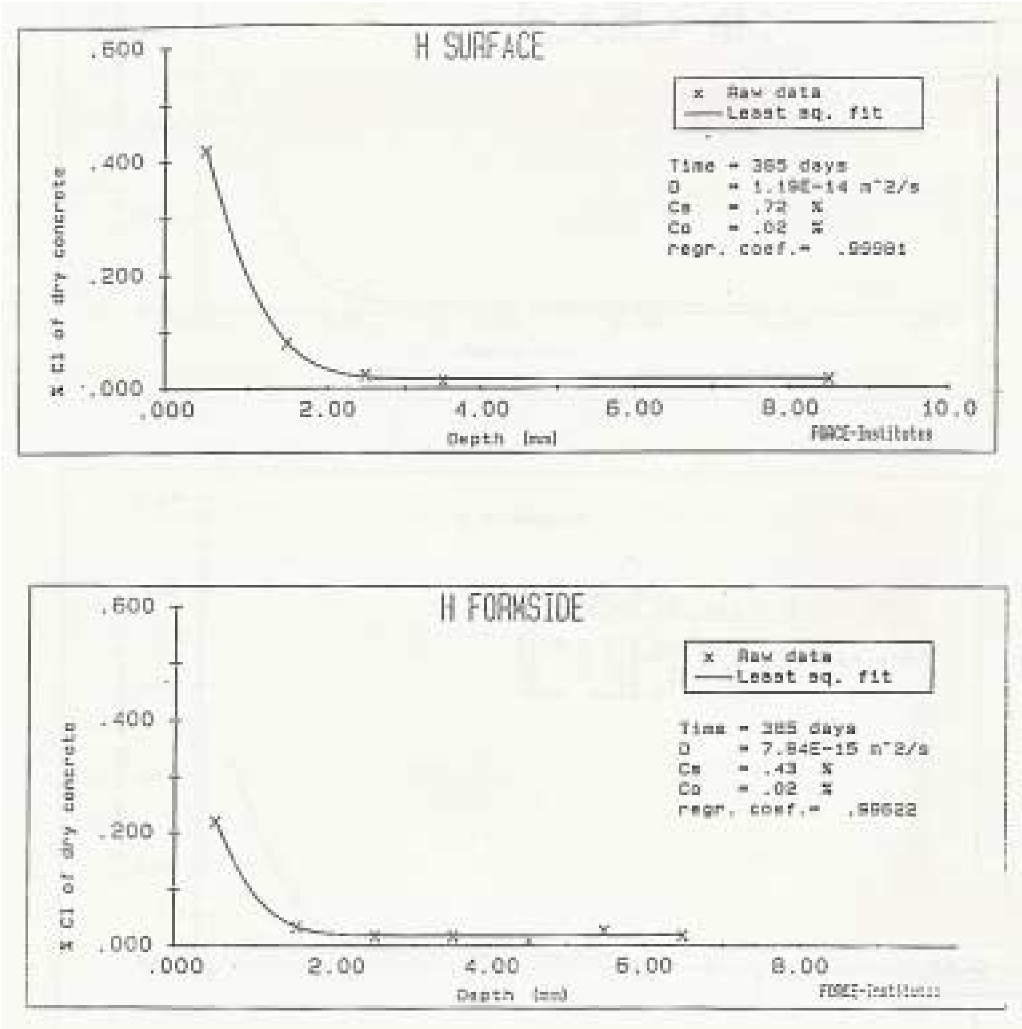

Figure 3 Chloride profiles measured on beam with 1 mm center deflection – corresponding to a bending stress of 42 MPa – after approximately 1 year of exposure.

On fig. 3 is shown chloride profiles taken from a beam with 1 mm center deflection. Force Institutterne measured permeability rates from 0.8 to $2.3x10^{-14}$ m^2/sec. The higher rates were measured at early ages, and permeability rates decreased with exposure time, indicating that the rate of chloride penetration is not a constant, but that it decreases with time because of a “clogging” effect – an observation that has also been made for other types of high performance concrete. The chloride profiles measured were not influenced by the loading of the beams.

Cracks – and salt in the mixing water

No observations of rebar corrosion were made for the more ”conventional” tests on chloride exposure, which led to initiation of further investigations. These further investigations included tests, where salt was added to the mixing water during casting of the beams (3.2% NaCl by weight of cement) but again no corrosion was observed as the lack of capillary porosity prevented transport of water and oxygen.

Tests have also been carried out where the reinforced beams were loaded up to yielding – a load of close to 130 kN – so that substantial cracks developed, after which the beams were again exposed to salt water. In these cases the cracks closed up as they were filled with hydration products. This is due to the large content of unhydrated cement grains. These unhydrated grains react with the water entering the crack. This has been confirmed through thin section and XRD analysis [3]. The cracked beams were exposed for up to 4 years at Force Institutterne in a wetting and drying cycle and in no cases have rebar corrosion been observed.

Also at Instituto Eduardo Torroja a number of the exposed beams have had visible cracks. The beams tested in Spain only had 4 rebars and only in the tensile zone as compared to the beams tested at Force Institutes, that had 5 rebars in the tensile as well as the compressive zone of the beam. An example of a cracked beam is shown in fig. 4. The width of the shear cracks was 1 mm. In the tests in Spain the whole beam was not submerged – as at Force Institutterne – but the test was carried out as a ponding test, where a silicone strip was placed around the circumference of the bottom part of the beam where the cover to the rebars was 10 mm. Inside this strip salt water was placed and this salt water was replaced periodically due to evaporation. The tests at Instituto Eduardo Torroja continued for 3 years and again there were no observations of rebar corrosion.

Carbonation

Carbonation tests have also been carried out and even with accelerated test methods there is only superficial carbonation – a few hundred microns - after several years of testing. In tests at Instituto Eduardo Torroja specimens were exposed to natural carbonation as well as to chambers with 100% CO_2. In earlier tests at Force Institutterne beams were exposed for a few years to an atmosphere with a concentration of CO_2 50 times higher than natural exposure and with a relative humidity between 55 and 60% [5].


DEFLECTION BEAM 3mm


DEFLECTION BEAM 3mm

Figure 4 Beam with center deflection of 3 mm prior to salt water exposure.

References

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3. **Soler, Laura**, "Microcracking Effects on CRC Durability". Brite/EuRam Fellowship study, CBL Report No. 53, Aalborg Portland A/S, December 1995.

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