Chlorine migration in concrete

In many applications concrete reinforced with steel rebar may come into contact with salt containing solutions. This applies certainly to concretes in maritime environment like ports, bridges and piers but can also affect inland regions through de-icing salts. Moderate environments can also be damaged as can be seen with the collapsed garage on the photograph (1).

Figure 1 Collapsed garage.

When a concrete structure is often exposed to de-icing salt, salt splashes, salt spray, or seawater, chloride ions from these will slowly penetrate into the concrete, mostly through the pores in the hydrated cement paste. The chloride ions will eventually reach the steel and then accumulate to beyond a certain concentration level, at which the protective film is destroyed and the steel begins to corrode, when oxygen and moisture are present in the steel-concrete interface (2).

Chloride ion diffusion is dependent on water being present in mortars and concrete. The water content present is dependent on the pore volume and the environment of the concrete (3).

Through the denser cement matrix produced using Metaver, the diffusion of chlorine may be reduced to acceptable lower levels.

Testing the chlorine diffusion in concrete is therefore of great importance. Reducing the diffusion level will greatly extend the working life of concrete. The most accepted test to measure the chlorine diffusion is actually the NT BUILD 492 Nordtest method (4).
This test defines the chloride penetration resistance as in the table 1:

Chloride penetration resistance	**Dcl [m^2/ s]**
Very good	$Dcl < 2 \times 10^{-12}$
Good	$2 \times 10^{-12} > Dcl < 8 \times 10^{-12}$
Medium	$8 \times 10^{-12} > Dcl < 16 \times 10^{-12}$
Poor	$Dcl > 16 \times 10^{-12}$

Table 1: Chlorine diffusion definition.

To determine the effect of our Metaver Type I in concrete, the Faculty of Civil Engineering of the University of Zagreb have been asked to perform tests. In these tests Metaver Type I replaced 8% resp. 12% of a typical CEM I 42.5 R at a water/binder ratio of 0.39 and 0.35 to define the influence of chlorine diffusion.

The mixes are described in the table 2 showing also the compressive strength at 28 days:

Concrete composition

Designation of concrete	M 1	M 2	M 3	M 4	M 5	M 6
Component composition, name or origin of the component's composition	The composition of concrete for 1 m^3 (kg/m^3 concrete)					
Cement CEM I 42.5 R,	380	350	335	390	360	345
Metaver I	-	30	45	-	30	45
Water, urban water supply	148	148	148	136	136	136
Crushed aggregate 0-4 mm	927	927	927	935	935	935
Crushed aggregate 4-8 mm	279	279	279	279	279	279
Crushed aggregate 8-16 mm	652	652	652	654	654	654
Superplastisizer, Glenium Sky 510 BASF	3.8	5.7	7.6	-	-	-
Superplastisizer, Glenium Sky 51 BASF	-	-	-	3.1	3.9	4.7
Water-cement ratio	0.39	0.39	0.39	0.35	0.35	0.35
Short description of the mixture	Concrete without Metaver	Concrete with 8% Metaver	Concrete with 12% Metaver	Concrete without Metaver	Concrete with 8% Metaver	Concrete with 12% Metaver
Medium compressive strength after 28 days (N/mm^2)	74.4	88.0	91.4	83.7	95.9	100.3
Medium chloride diffusion coefficient after 28 days ($\times 10^{-12}$ m^2/s)	9.61	2.53	**1.37**	7.04	1.43	**0.90**

Table 2: Metaver Type I test results (5).

The results show that the amount of water used in the preparation of the concrete influences the final strength and on the chlorine diffusion, as more water leads to more pores.

It shows that the increased use of Metaver will give a higher compressive strength after 28 days as the matrix becomes denser.

The denser matrix will also reduce the chlorine migration in the concrete by increasing its durability. It shows that with the replacement of 12% of the cement in concrete with w/b=0.39, the chloride penetration resistance goes from “medium” to “very good”.

With a lower w/b ratio of 0.35 the replacement of even 8% of the cement will move the concrete from “good” to “very good”.

These data show that the resistance to chlorine is greatly increased in concrete structures prone to salt attacks. Using Metaver reduces chlorine migration and may bring additionally the following advantages:

- a more environmentally friendly binder (less CO_2 developed)
- an enhancement of the early strength of CEM II slag cements
- a denser concrete
- a lower water uptake
- a better chemical resistance
- an increased durability
- a reduced efflorescence
- a better adhesion to substrate and fibers
- a lighter color
- a better water retention (guaranteeing full hydration)
- a reduction of ASR in concrete

Literature cited:
(1) Neal Steven Berke, Victor Chaker, David Whiting, ASTM Committee G-1 on Corrosion of Metal
(2) http://corrosion-doctors.org/Concrete/Nature.htm
(3) www.metakaolin.info
(4) http://www.nordicinnovation.net/nordtestfiler/build492.pdf
(5) Table 2: Professor Dr. Marijan Skazlic, University of Zagreb, Faculty of Civil Engineering, Croatia