Case 5.1 Curing of the cover layer evaluated by Pullout and Bulk Resistivity and the implication on service life, Denmark

For resistance to chlorides from e.g. the sea or deicing salts, the cover layer is the "Peel of the Orange", protecting the reinforcement against corrosion. Similar with carbonation. This "PEEL" is the essential part of a new structure when it comes to durability, not the interior. To achieve a good, durable cover layer, the right mix has to be used on-site, it has to be well compacted, have a sufficient thickness and be well cured. Optimal curing is providing water or keeping the formwork on during hydration, alternatively using internal curing with LW fine aggregates or water absorbent polymers, while less efficient curing is achieved if curing compounds or plastic sheets are applied. No curing has significant detrimental effects, as does exposure to high temperature and wind (miscuring).

The PEEL

Early Danish research in 1969 at DTU showed a 31% reduction in LOK-TEST pullout strength for a w/c-ratio of 0.36, and 40% for a w/c-ratio of 0.50 when concrete is miscured (wind and higher temperatures) compared to water curing at 20^0C

This is strength, but how about the resistance to chlorides?

Comparison between pullout strength and bulk conductivity has been performed for estimating the chloride diffusivity – and service life – for simplicity only between **wet cured** and **air cured** concete.

The two standards applied was:

ASTM C900-19: "Standard Test Method for Pullout Strength of Hardened Concrete", for compressive strength

ASTM C1876-19: "Standard Test Method for Bulk Electrical Resistivity or Bulk Conductivity of Concrete", for testing of slices of water saturated cores, estimating the diffusion coefficient and the service life.

The concrete used: C40/C50 aggressive class concrete (f'_c 40 MPa on cylinders, 50 MPa on cubes)**,** testing after 56 days.

ASTM C900-19
LOK-TEST Pullout force in kN, testing depth 25 mm

ASTM C1876-19
MERLIN Bulk Resistivity in Ωm of saturated 50 mm core from cover layer

The average results from testing of three sets of specimens (wet and air cured) were:

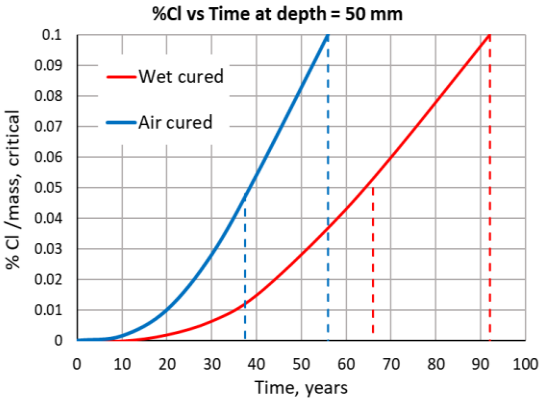
Curing	LOK-TEST
Wet cured	42.7 kN
Air cured	33.0 kN

Curing	Resistivity
Wet cured	**r = 166 Ωm**
Air cured	**r = 111 Ωm**

NDTitans in action

MERLIN resistivity testing of the 50 mm cover layer for the two curing conditions resulted in 166 Ωm for wet curing and 111 Ωm for air curing. These resistivity values can be transformed to a chloride diffusion coefficient, D_a, using the Nernst-Einstein relation. Wet curing corresponded to a chloride diffusion coefficient of 27.2 mm^2/y and air curing to 41.5 mm^2/y.

By means of the **Life 365™ Software**, based on Fick's second law of diffusion, the expected service life in years, t, can then be estimated for a given cover layer and exposure condition.



Critical Chloride level	Service life	
	Wet curing	Air curing
0.050% Cl^-/mass	66 years	37 years
0.100% Cl^-/mass	92 years	56 years

For a 50 mm cover layer and sea water splash exposure condition, the estimation show a 40% reduction of the service life regardless of the critical limit for corrosion of the reinforcement is considered to be 0.050% Cl- or 0.100% Cl- by concrete mass. For miscured concrete (wind and higher temperature), the reduction would be much larger.

LOK-TEST showed a 23% strength reduction
MERLIN a 33% reduction in bulk resistivity
Service life reduced by 40% in a splash zone of a sea structure

In this manner, a quick on-site strength test, the LOK-TEST or the CAPO-TEST, will immediately indicate the cover layer quality. If lower than expected, cores may be drilled out from the cover layer, sliced and water saturated for further testing with the MERLIN for bulk resistivity (or its inverse, conductivity) and estimating the remaining service life in chloride environment.

Examples of pullout used for cover layer quality:

Great Belt Link, Denmark

Cover layer accepted if the strength was minimum 80% of the potential lab strength

Supporting sea wall, Copenhagen

Air cured. Pullout strength 70% of lab strength

Garage parking structure, UK

Covered by heavy plastic sheet and wet mats. Pullout matched the lab strength

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