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Service de recherches et conseils techniques en matière de ciment et béton
Ricerca e consulenza tecnica per cemento e calcestruzzo
Technical Research and Consulting on Cement and Concrete

CH-5103 Wildegg
Lindenstrasse 10
Telefon 062 / 887 72 72
Fax 062 / 887 72 70
E-Mail: info@tfb.ch

Comparative investigations of the chloride resistance of concrete mixes

Summary

This research project had the following three goals:

- Comparison of the possible tests to characterise the resistance of concrete against chloride ions penetrating from the outside, the so called **chloride resistance**.
- Validation of the results of the laboratory concrete mixes with samples taken from older existing concrete structures exposed to chloride attack.
- Elaboration of recommendations for the testing and for the corresponding criteria for the assessment of the chloride resistance of concrete as a base for a SIA testing standard.

Within this project very extensive investigations have been carried out on the chloride resistance of a variety of concrete mixes with and without mineral admixtures. These led a wealth of knowledge and relations, partly known from the literature, could be confirmed. The following concrete mixes have been investigated:

- Common types of concrete (concrete with Portland cement, without mineral admixtures).
- Concrete mixes with fly ash
- Concrete mixes with silica fume
- Concrete mixes with ground granulated blast furnace slag.

Besides these laboratory mixes additionally concrete from other projects and specimens from existing concrete structures have been tested. The following tests have been used to characterise the chloride resistance of concrete (in parenthesis: of the test):

- ASTM-test according to AASTHO T259-80 (amount of electrical charge passed)
- ibac- or CTH-test (chloride migration coefficient)
- Streicher-test (electrical conductivity)
- gas permeability (permeability constant)
- water conductivity test according to the SIA testing standard SIA 162/1, test No. 5 with the modification of VPL (water conductivity)
- water suction test (chloride content or chloride enrichment)

In the following paragraphs the most important results of this study are summarised.

Influence of material parameters

- The investigation has shown that the composition of the concrete, especially the water to cement ration (w/c) and the water to binder ratio (w/B), respectively, as well as the type and content of the mineral admixture mainly determine the chloride resistance.

- The influence of the binder content, the maximum grain size of the aggregate and the chemical admixtures (superplastisizer) has not been systematically studied. It is rather small as it could be concluded from the comparison of the few data of the laboratory concrete mixes and from the concrete mixes of other projects. But, the number of results is too small and does not allow a sound finding.

- Between the chloride resistance and the other material parameters (e.g. w/c or w/B-ratio, porosity, compressive strength) no general relation which is valid for all types of concrete could be found. The materials parameters may give some guidance.

- Generally, the chloride resistance increases with the age of the concrete. According to their age the samples from existing concrete structures showed a moderate to high chloride resistance. But, the 28-days-values of the chloride resistance, calculated back from the actual values, are significant lower than those of the laboratory concrete mixes.

Determination of the chloride resistance

The ibac-test, the water conductivity test and, to a somewhat lower extent, the Streicher-test can be recommended as routine laboratory tests for the initial testing and the quality assurance of concrete as well as for the investigation of the concrete of existing structures (criteria: **Table 7.4**). The different tests are described in the **chapter 3 und 5.4**. After the evaluation of the various advantages and disadvantages the research group recommends to use the ibac-test to determine the chloride resistance in the future and to elaborate an SIA testing standard for this method. The following considerations have been of importance for this conclusion:

- The ibac-test reveals well reproducible results as the comparison of the results of this study with those of the literature showed. The results of concrete from existing structures go well together with those results. Additionally, this is the only one of the methods studied which provides a characteristic value for the simulation and the forecast of the development of the state conditions of structures as well as for the life cycle assessment. There is, further, a good chance that this test will be standardised as an EN standard.

- The main advantage of the water conductivity test is that this method is well known as SIA standard (SIA 162/1, test no. 5) and the important elements of the test procedure are regulated. It is unclear, however, how far the influence of the mineral admixtures is correctly determined and questions to the test procedure remained open (covering the side surfaces of the specimens or not?). This test has practically no chance to be published as an EN standard. Therefore, the water conductivity is limited or not suitable as a characteristic value of the chloride resistance of concrete. Further investigations would have to be carried out.

- The Streicher-test provides indeed no diffusion coefficient, but this test has the advantage that it can be used for chloride contaminated concrete. For concrete mixes with a very high chloride resistance this test seems to be more sensitive than the ibac-test, but its execution is more difficult. This method may be useful for the assessment of existing concrete structures exposed to chloride attack. But, it has practically no chance as an European test standard.

- Compared to the Streicher-test (and ASTM-test) the results of the ibac-test corresponded much better with the literature data. The systematic deviations of the results of the ASTM-test are probably caused by differences of the test procedures. Further work would be necessary.

- On the basis of the results of this study the gas permeability and the water suction can not be recommended to characterise the chloride resistance of concrete (**Table 7.3 and 7.4**).

Testing age

The time of testing should basically be fixed to 28 days. For important or large structures with very high requirements on the durability, especially on the chloride resistance, and for which concrete with blended cements (e.g. Portland cement with slag or fly ash) or with mineral admixtures are used, tests at a higher age (e.9. 90 days) should be carried out during the evaluation phase.

The improvement of the chloride resistance of concrete with the age is positive and provides a certain safety factor for the uncertainties of the execution. This safety factor should, therefore, not be consumed by a higher testing age.

Concrete with a high chloride resistance

The comparison of the results of laboratory concrete mixes with those of the investigations of existing concrete structures showed that the requirements on the chloride resistance has to be fixed on a rather high level in order to achieve a sufficient durability (**Table Z.1**).

Exposure class according to SN EN 206-1:2000		**Concrete cover**	
		40 to 50mm	**70 to 80mm**
	Description of the environment:	**Admissibile single values of the migration coefficient, m^2/s**	
XD 1	Contact with airborne chlorides	≤20 10^{-12}	no requirement (≤40 bis 60 10^{-12})
XD 2	Permanent contact with chloride containing water	No provisions because of the lack of experience (recommandation: as XD 3)	
XD 3	Contact with spray water with chlorides	≤10 10^{-12}	≤20 bis 30 10^{-12}

Table Z.1: Recommendations for admissible single values of the 28-days-migration coefficient of concrete for the exposure class XD (chloride induced corrosion).

In order to reach the admissible single values given in **table Z.1** under practical conditions the scatter of the testing and material has to be considered. The target average value has, therefore, to be reduced by approximately 1/3.

A high to a very high chloride resistance may be achieved by:

- reduction of the w/c-ratio (≤0.40).
- for w/B-ratios between app. 0.4 and 0.5 by the addition of
  - silica fume, already at a low content of 7M.% related to the cement content
  - rather high contents of fly ash (over app. 30M.%) or slag (app. 60M.%)
  - or corresponding blended cement types

The positive influence of fly ash and slag often found in the literature could only partly be confirmed in this study. The effect of these two mineral admixtures depends not only on the content but also on various other factors as e.g. on the reactivity, on the source and type of addition (addition to the clinker milling process or admix to the cement in the cement kilns or addition to concrete mix), on the w/B-ratio, eventually on the cement type and cement strength class as well as on the possible interactions between cement, chemical and mineral admixtures (e.g. grain size distribution). In any case appropriate qualification tests have to be carried out in advance.

Although very extensive investigations have been executed so far there is still a lack of knowledge in some areas. Further research work is needed in order to have sufficient knowledge and experience for new construction as well as for the rehabilitation of concrete structures and to reach the goal of zero-maintenance. In **chapter 8** some topics for further research are listed.

Some practical recommendations are given in **chapter 9**.

Dr. F. Hunkeler, Dr. Ch. Merz und H. Ungricht, TFB, Wildegg

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Order information: VSS, Seefeldstrasse 9, 8008 Zürich.