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Field Tests of Chloride Penetration into Concrete with Microsilica

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ABSTRACT
Ten concrete bocks 150 × 150 × 150 cm of five different concrete qualities were placed in the tidal zone in Østmarkneset in the Trondheimsfjord, Norway, in March 1983. The concretes were strength classes C35, C65 with 10 and 20% microsilica. All blocks had reinforcing nets with 30 mm and 50 mm cover.

In addition to visual inspection the following measurements were made: surface potentials, concrete resistivity, chloride profiles and accelerated chloride penetration test.

From one of the blocks of each concrete quality the chloride profiles were determined both from the side facing land (south) and from the side facing the sea (north).

The amount of penetrated chlorides is relatively identical for all types of concrete. The C65 concrete with 10% microsilica contains most chlorides, 380 gm^{-2} surface, while the C35 concrete with 20% microsilica shows the least chloride penetration, 217.8 gm^{-2} surface.

The penetrated amount is about the same from the land side as from the sea side (exception for C35 concrete with 20% microsilica shows twice as much penetration from the sea side).

The shapes of the profiles are very different for the types of concrete. Dense concretes show steep profiles with a high chloride content at the surface and limited penetration while more open concrete shows flat profiles with less chloride in the surface but deeper penetration.

In the accelerated testing C35 shows a marked effect of the microsilica content on the chloride penetration, as expected. This is reasonable and reflected also in the field result for one of the specimens without microsilica, while the other specimen without microsilica shows a remarkably low chloride penetration compared to the specimens containing microsilica.

1. Introduction

In 1982 Elkem Materials initiated construction of 10 concrete blocks 150 × 150 × 50 cm of five different concrete qualities to be placed (March 1983) in the tidal zone at Ostmarkneset in the Trondheimsfjord.

The concretes were strength class C35 with 0, 10 and 20% microsilica and C65 with 10 and 20 % microsilica. At the time of construction there was a lot of discussion in Norway about the effect of microsilica on the corrosion protective properties of concrete, especially on the chloride penetration into concrete. All blocks (two blocks of each quality) had reinforcing nets with 30 mm and 50 mm cover. The nets had external electrical connections. The set-up and material data have been reported earlier. The investigation presented in this report was made September 1997. In the evaluation of the condition much weight has been given to the developments since the earlier investigations.

2. Test Programme

In addition to visual inspection the following measurements have been made: chloride profiles and accelerated chloride penetration, surface potentials and concrete resistivity. The chloride profiles was determined at drilled cores by 2 mm slices. The accelerated test (submerged test according to NT Build 443) where made at the inner part of the core. The surface potentials (corrosion potential of the embedded nets) were measured using a copper/copper sulfate reference electrode. Resistivity was measured by the Wenner method with four drilled-in bolts at 100 mm separations and a 50 mm depth.

3. Results and Discussion

Algae and shells covered all blocks from top to bottom but little physical damage were observed, except for some frost damages at the corners. Most of the electrical connections were destroyed, however, and were renewed.

From one of the blocks of each concrete quality the chloride profiles were determined both from the side facing land (south) and from the side facing sea (north). All profiles are presented in Fig. 1. The amounts of chlorides penetrated are also presented as grams of chlorides per m^2 concrete area (the area of the chloride profile) in Table 1.

As shown in the Figure the shapes of the profiles are very different for the types of concretes. Dense concretes show steep profiles with a high chloride content at the surface and limited penetration while more open concrete shows flat profiles with less chloride in the surface but deeper penetration. The extremes are — naturally — C35 without microsilica as the less dense concrete and C65 with 20% microsilica as the densest concretes.

The penetrated amounts of chloride are, however, relatively identical for all types of concrete. In fact, the C65 concrete with 10% microsilica contains most chloride, 380 gm^{-2} surface, while the C35 concrete with 20% microsilica shows least chloride penetration, 217.8 gm^{-2} surface. The penetrated amount is about the same from the land side as from sea side (exception for C35 without microsilica, which shows twice as much penetration from the sea side).

Two cores of each concrete quality were subjected to immersion testing of chloride penetration according to NT Build 443. The results are shown in Table 2.

At two points an important difference between the field results and accelerated laboratory testing is observed. In the accelerated testing the C35 shows a marked effect of the microsilica content on the chloride penetration — as expected — and as

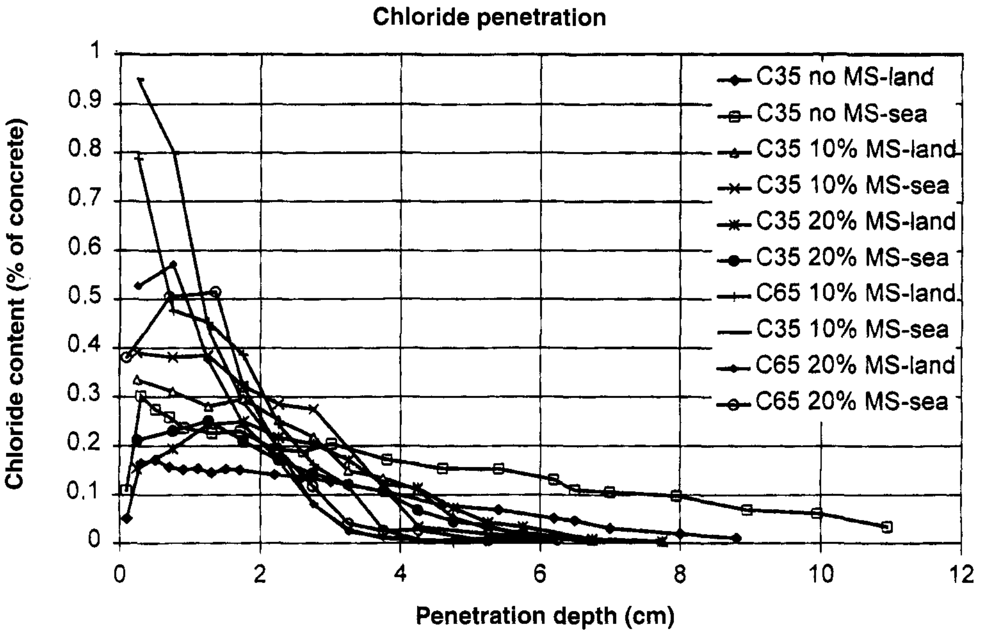

Fig. 1 Chloride profiles (MS = microsilica).

Table 1. Penetrated amount of chlorides

Concrete quality	Direction	Penetrated amount (g Cl^-/m^{-2}) Individual	Mean
C35 no microsilica	Facing land Facing sea	192.9 386.2	289.6
C35 10% microsilica	Facing land Facing sea	286.6 249.7	268.1
C35 20% microsilica	Facing land Facing sea	232.7 202.8	217.8
C65 10% microsilica	Facing land Facing sea	367.3 392.7	380.0
C65 20% microsilica	Facing land Facing sea	284.0 273.4	278.7

shown in Fig. 2. This is reflected also in the field result for one of the specimens without microsilica, while the other specimen without microsilica shows a remarkably low chloride penetration compared to the specimens containing microsilica.

Table 2. Results from immersion chloride penetration test

Concrete quality	Surface concentration (% of concrete)	Diffusion constant (10^{-12} m^2 s^{-1})	Penetrated amount (g m^{-2})
C35 no microsilica	0.90	28.85	240.35
C35 10% microsilica	1.05	6.02	144.2
C35 20% microsilica	0.85	7.07	139.7
C65 10% microsilica	0.948	4.04	113.3
C65 20% microsilica	0.998	2.48	95.7

The second deviation between field and laboratory data is for the C65 concrete with 10% microsilica. While the field data show high chloride contents in the surface area, this is not observed in the laboratory testing.

The surface potential values are compared to corresponding values from the 1992 survey. The potential values of 1997 are definitely more negative than the values of 1992. While the most negative mean value in 1992 was –349 mV and the least negative mean value –40 mV the corresponding results in 1997 were –666 mV as the most negative and –109 mV as the least negative referred to the Cu/$CuSO_4$ electrode.

It is worth noting that the most negative result in 1992 was measured for the presumably densest concrete (C65 with 20% microsilica) and the least negative result was measured for the presumably least dense concrete (C35 without microsilica). This illustrates how difficult it is to draw conclusions with respect to state of corrosion based only on potential measurements. The potential values might be very low but

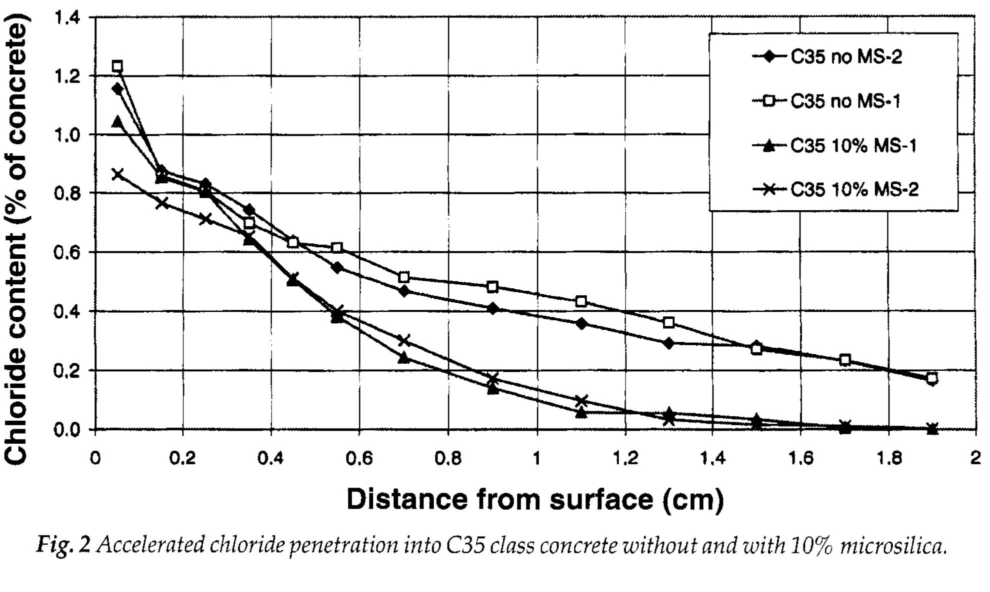

Fig. 2 Accelerated chloride penetration into C35 class concrete without and with 10% microsilica.

the chloride content is almost negligible and corrosion cannot have been initiated.

In other cases the chloride content is high without causing a negative potential.

The resistivity values measured in 1992 and 1997 are presented in Table 4. For all concretes except C35 without microsilica there is a considerable increase in the resistivity from 1992 to 1997 with a 30% increase as typical.

Table 3. *Mean values for surface potentials (mV vs* $Cu/CuSO_4$*) in 1992 and 1997*

Concrete quality	Land side (South) 30 mm cover				Sea side (North) 50 mm cover			
	I		II		I		II	
	1992	1997	1992	1997	1992	1997	1992	1997
C35	–215	–609	–256	–666	–40	–124	–256	–313
C35 10% microsilica	–265	–399	–278	–375	–148	–319	–100	–285
C35 20% microsilica	–257	–383	–353	–551	–77	–361	–330	–400
C65 10% microsilica	–273	–329	–234	–326	–78	–390	–65	–127
C65 20% microsilica	–82	–109	–349	–319	–78	–211	–249	–295

Table 4. *Resistivity measured in 1992 and 1997 (Ω m)*

Concrete quality	Land side (South) 30 mm cover				Sea side (North) 50 mm cover			
	I		II		I		II	
	1992	1997	1992	1997	1992	1997	1992	1997
C35 no microsilica	42	41	40	36	42	57	40	40
C35 10% microsilica	173	238	200	271	217	266	176	206
C35 20% microsilica	254	326	180	244	251	290	251	258
C65 10% microsilica	252	330	300	385	318	344	341	402
C65 20% microsilica	371	482	466	417	451	593	421	487

4. Conclusions

The field data and laboratory data on chloride penetration do not correspond fully. While the laboratory data show a definite effect of microsilica in reducing the chloride penetration the field data are not so distinctive. They show a small effect of MS on the amount of penetrated chlorides but a very clear effect on mechanism of penetration. The MS containing concretes have a steeper profile with higher chloride content in the surface and smaller penetration depth. This effect was most marked with 20 % MS.

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