CORROSION PREVENTION OF CONCRETE REINFORCEMENT BY EPOXY COATING

Liisa Salparanta
Technical Research Centre of Finland
Concrete and Silicate Laboratory
MScTech, Research Scientist

SYNOPSIS

In this study the corrosion prevention ability of one powder epoxy coating applied by electrostatic spraying and three liquid epoxy paints was studied.

The powder epoxy coating and the coal tar epoxy paint turned out to have a good corrosion prevention ability, but the other two liquid epoxy coatings even increased corrosion in some cases.

In addition the thickness and evenness of the powder epoxy coating were examined.

Key words: epoxy coatings, concrete reinforcement, corrosion protection.

1. INTRODUCTION

One of the methods of preventing concrete reinforcement corrosion is epoxy coating of the reinforcement. There are two types of epoxy coatings: liquid coatings and powder coatings. It has been proven that powder epoxy coatings surpass liquid coatings in corrosion protection and also in other properties /1, 4/.

The first concrete structure to have epoxy-coated (powder) reinforcement was a bridge built in the USA in 1973 /3/. Even today in the USA epoxy-coated reinforcements are mainly used in bridge building.

Today the use of epoxy-coated reinforcement in the USA has spread to fields other than bridge building, including rebuilding, and the use of epoxy coating is fairly common. The performance of the epoxy coated steel bars especially in bridge decks has indicated a significant increase in protection and reduction of cracking of the cover during the fifteen years since this method was introduced /5/. Nowadays this method has spread also to Europe.

2. EPOXIES

Epoxy coatings that were included in this study were:

- one powder epoxy coating applied by electrostatic spraying
- a commercial coal tar epoxy paint, CTE
- a commercial water dispersible epoxy paint WDE and,
- a water tolerant glass flake filled epoxy paint formulated in a laboratory, Essiflake 781.

3. TESTS

3.1 Body of the test programme

The study consisted of two parts: the tests on the coating and the corrosion tests.

The body of the test programme was as follows:

coating tests (carried out on powder epoxy coating only):

- measurements of thickness and evenness of the coating

corrosion tests:

- corrosion tests on coated bars in sound grout cylinders
- corrosion tests on coated bars in cracked concrete cylinders
- corrosion tests on coated bars in cracked concrete beams under repeated tensile stress (powder epoxy coating only).

The test bars with powder epoxy coating were ribbed bars and those with liquid coating were smooth bars.

All the corrosion tests are still under progress. The corrosion tests on small cylinders are planned to last for ten years and the test results after only two years curing have been obtained so far. No results on large scale beams have been obtained yet because the condition of two reference bars examined after 1.5 and 3 years from the beginning of the test showed only minor corrosion and therefore no other beams were examined.

3.2 Thickness and evenness of the coating (powder epoxy)

Epoxy coated deformed bars were cut transversely and longitudinally and the cuts were examined under a microscope.

The coating thickness aimed at was 250 μm. Microscopic examination revealed that the coating thickness varied from 50 μm to 250 μm. The coating thickness was usually at its thinnest on top of the ribs and at its thickest next to the ribs.

3.3 Corrosion tests with small concrete grout cylinders

The corrosion of the test bars of different grades embedded in concrete or grout cylinders partly immersed in tap water or synthetic sea water was examined. The steel grades consisted of undamaged coating, coating with a coating defect, and no coating. Part of the cylinders were prepared with 4 % $CaCl_2$ addition (by weight of cement) and part of the cylinders had a crack running transversely through the specimen at the exact point of the coating defect. The test specimens are illustrated in Figure 1.

The level of the curing solution was altered weekly during the first two months, and then monthly, in such a way that for half the time the intentional coating defect lay below the water and half the time above. The curing solution was changed every time the level of the solution was raised.

For the examination of bar condition three parallel cylinders were broken each time upon examination and the coating was stripped from the steel surface. The condition of the test bars was examined visually. The degree of damage was evalued on the basis of the intensity and area of corrosion.

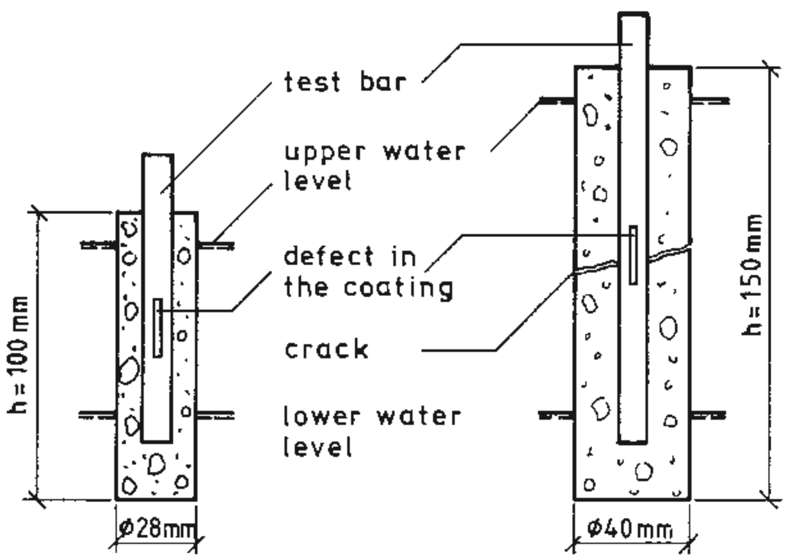

Fig. 1. Test specimens used in the corrosion tests with small cylinders.

Table 1 shows the curing conditions and the steel grades of the corrosion tests.

Table 1. Curing conditions and steel grades of the corrosion tests on small cylinders.
t = tap water
s = synthetic sea water

Specimen	Bars embedded in sound grout cylinders t	s	$CaCl_2$ - addition s	precracked concrete cylinders t	s
powder epoxy, ribbed bars:					
sound coating	x	x	x	x	x
coating with a defect	x	x	x	x	x
no coating	x	x	x	x	x
CTE, WDE, Essiflake 781, plain bars:					
sound coating		x	x		x
coating with a defect		x	x		x
no coating		x	x		x

3.4 Test on epoxy-coated reinforcement in concrete in chloride-containing environments under repeated tensile stress

For the test 10 reinforced concrete beams were prepared. Three steel grades were used: undamaged powder epoxy coating, powder epoxy coating with an intentional coating defect and no coating.

The dimensions, reinforcement and location of the intentionally made coating defects of the test beams are illustrated in Figure 2.

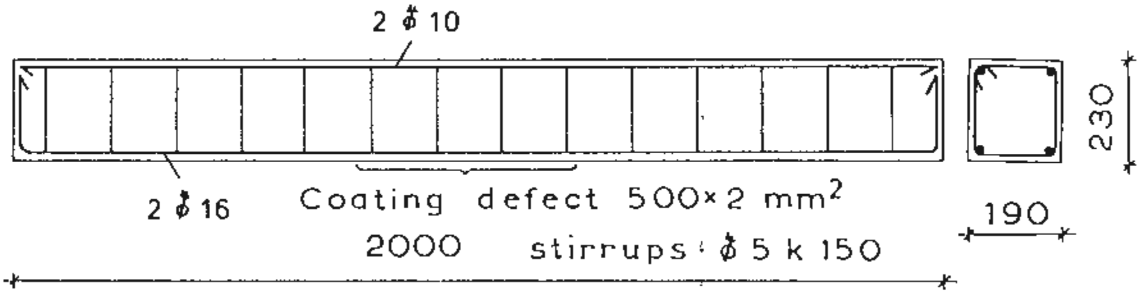

Fig. 2. Test specimens, dimensions in mm.

Before starting the corrosion test each freely-supported beam was loaded with a static point load acting at the midspan to such a value that the width of the largest crack in the beam was about 0.3 mm.

At the age of about 4.5 months a load was concentrated symmetrically on the beams through two line loads. Test arrangements are graphically depicted in Figure 3.

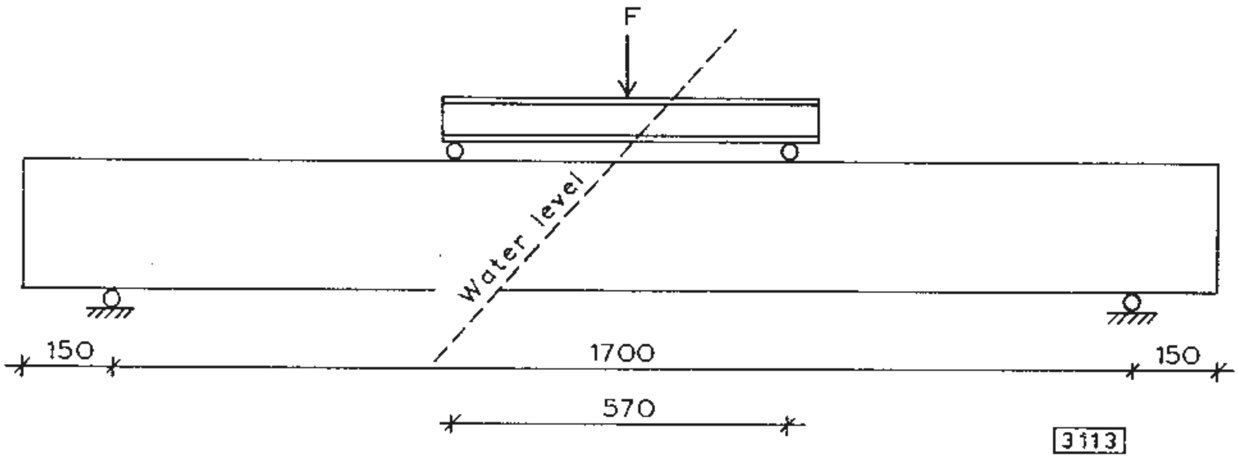

Fig. 3. Loading arrangements of pretreated test beams partly immersed in synthetic sea water at an inclination of 45^0 dimensions in mm.

Each beam was loaded and unloaded about 7.5 times per minute. The peak value of the repeated load was of such a nature that the stress of the tension bars turned out to be approximately 200 N/mm^2 for the first 2 months and later some 150 N/mm^2 at each loading cycle. A diagram of the duration of the corrosion test is plotted in Fig. 4.

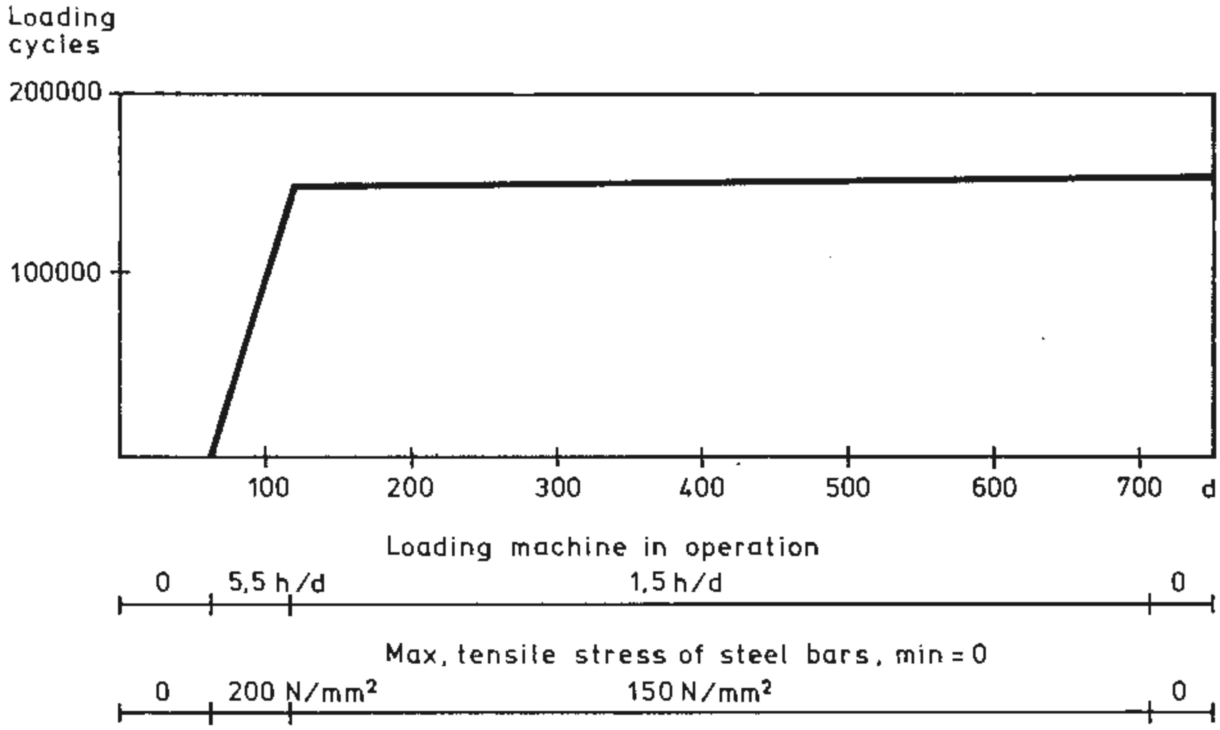

Fig. 4. A cumulative graph showing the number of loading cycles during the test.

Following the corrosion test the diagrams of cracks in the beams are plotted, the bars are removed from the beams and they are examined visually and finally fatigue test is performed with the bars.

4. CORROSION TEST RESULTS

The condition of the test bars in small cylinders is presented in table 2.

The first beam with uncoated reinforcement was examined after 1.5 years and the next one after 3 years from the beginning of the test. Only minor corrosion was observed at the exact points of the cracks in the beams above the water level. No other beams were examined.

There are still 8 beams in the sea water bath. 3 beams have reinforcement with sound epoxy coating, 3 with epoxy coating with a defect and 2 beams have uncoated reinforcement.

Table 2. Condition of corrosion test bars in small cylinders

-	bars not examined		a	sound coating
+	no corrosion		b	coating with a defect
++	minor corrosion		c	no coating
+++	some corrosion		t	tap water
++++	corrosion		s	synthetic sea water
+++++	strong corrosion			

Curing time	coating	steel grade	sound cylinder No $CaCl_2$ addition t	s	$CaCl_2$ addition s	precracked cylinder No $CaCl_2$ addition t	s
6 months	powder epoxy	a	+	++	++	+	+
		b	++	++	++	+	++
		c	+	+	+	+	++
	CTE	a		+	+		++
		b		+	++		++
	WDE	a		+++	++++		++++
		b		+++	++++		+++
	Essif-lake 781	a		++	+++		+
		b		++++	+++		++
		c		+	++		+
1 year	powder epoxy	a	+	+	+	+	++
		b	+	++	++++	+	+++
		c	+	++	+++	+	++
	CTE	a		++	++		++
		b		++	++		+++
	WDE	a		++++	++++		+++
		b		++++	++++		++++
	Essif-lake 781	a		++++	+++		++
		b		++++	++++		+++
		c		++	+++		+++
2 years	powder epoxy	a	+	++	+	+	++
		b	+	++	++	+	+++
		c	+++	+++	+++	++	+++
	CTE	a		++	++		++
		b		-	-		+++
	WDE	a		++	++		+++
		b		-	-		++
	Essif-lake 781	a		+++	+++		++
		b		-	-		+++
		c		-	-		++

5. DISCUSSION ON THE CORROSION TEST RESULTS

On the basis of the corrosion test results obtained so far the powder epoxy coating and coal tar epoxy coating have prevented corrosion effectively even in aggressive environment (concrete containing $CaCl_2$ and test specimens partly immersed in synthetic sea water), but they have not totally hindered it. The water dispersible epoxy paint and the water tolerant glass flake filled epoxy paint have even increased corrosion in some cases.

The coating defect (2 x 20 mm^2) has impaired the corrosion prevention ability of the coatings. In the case of the coating with a defect corrosion has normally concentrated around the coating defect. In some cases the test bars with a coating defect have corroded even more than the reference bars.

None of the coatings in this test is totally impermeable. All of them are pervious not only to water but also to chloride-ions.

The cracks in the concrete cylinders have not increase corrosion. Obviously the cracks have "healed" when calcium hydroxide from the neighboring concrete has leached into it.

Sea water curing has increased steel corrosion remarkably as was expected.

6. CONCLUSIONS

The test results obtained after two years curing revealed that some epoxy coatings prevent corrosion efficiently, some may even increase it. The powder epoxy-coating and the coal tar epoxy paint turned out to have good corrosion prevention ability also in aggressive environment, but neither of these coatings has hindered corrosion totally. The good corrosion prevention ability of fusion bonded powder epoxy coating as well as coal tar epoxy coating have been reported in literature /2, 3, 4, 6/.

Because the corrosion prevention ability of epoxy-coating is based on preventing the aggressive matter from getting into contact with the steel surface the integrity of the coating is required for its effectiveness of corrosion prevention ability.

It is necessary to carefully clean and roughen the steel surface before coating to achieve good adhesion between the coating and the steel surface.

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