ZINC-COATED CONCRETE REINFORCEMENT

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In this research, the durability of reinforcing steelbars as to their transportation, storage and bending were examined, together with chemical reactions between galvanization and fresh concrete and their prevention by chromate treatment of the zinced bar. Bond between the deformed bar and concrete and the durability of the reinforcement of reinforced concrete beams in corroding salt water under repeated load were also studied.

On the basis of the tests it could be established that the zinc sprayed and hot-dip galvanized bars endured well the transportation and storage, as well as the bending of the main reinforcement in accordance with the Standard Codes, but in bending the stirrups with small radius some cracking in galvanization is produced. The reactions between the fresh concrete and galvanization evolving hydrogen decrease the bond between the concrete and the deformed reinforcing bar, but the reactions can be prevented by means of passivation treatment in which the bars are immersed after galvanization in a 2 % of $K_2Cr_2O_7$-water solution for one minute and the bars are washed with water afterwards and the hot-dip galvanized deformed bars, treated by passivation is approximately the same as that of the untreated bar and the bond strength of the zinc sprayed bars about 40 % smaller than that of the untreated bar.

1. NEED TO USE ZINC-COATING IN REINFORCEMENT

If the bare steel is immersed in alkaline solution it will acquire a thin oxide film which protects the metal against further reaction. The film may be porous and may vary in thickness, but provided the solution remains alkaline, the steel will not corrode. The risk of corrosion is increased considerably if the alkalinity is decreased under pH value 10, for example due to

- absorption of acidic gases from the atmosphere

- splitting of cracking of the concrete over
- porous, poorly compacted concrete
- carbonatisation of concrete

Furthermore some inhibitors like chlorides increase the risk of corrosion considerably.

The risk of corrosion is largely associated with the environment, being greater in marine conditions and in the surroundings polluted by industrial smoke.

A common method to prevent the corrosion of the reinforcement is to use zinc-coated bars.

In the research completed at the Technical Research Centre of Finland use was made of
- hot-dip galvanized deformed bars,
- shot-peened zinc sprayed deformed bars and
- uncoated deformed bars as comparision.

2. EFFECT OF ZINC ON THE MECHANICAL PROPERTIES OF REINFORCEMENT

It was found that statical strength properties of hot-rolled bars did not change significantly, but the 0.2-limit of the cold-worked bars decreased after hot-dip galvanization.

In the research work /5/, it was found that the fatigue properties of deformed bars after hot-dip galvanizing are lower than those of uncoated bars. This is because the hard and brittle zinc-iron layer from where the cracks spread into the bar itself. It would be preferable to examine a situation in the corrodive environment. In this case a hot-dip galvanized bar in concrete has 8 % higher fatigue strength than uncoated bars. The relative increase in fatigue strength was highest in the case of shot peened [1] zinc sprayed bars, which is shown in the table 1.

Table 1. Fatigue properties of different kinds of bars /5/.

Treatment of bars	Relative value of the fatigue strength %
Uncoated bar in air	100
Uncoated bar in concrete	124
Hot-dip galvanized bar in concrete	134
Zinc sprayed bar in concrete	176
Shot peened, zinc sprayed bar in concrete	266

1) shot peened the surface of the bar is shot with small steel balls before zinc spraying

3. BEHAVIOUR OF ZINC-COATED REINFORCEMENT IN CONCRETE

3.1 Chemical behaviour

3.1.1 Reactions between zinc and concrete

Zinc belongs to the group II b of the periodic table of the elements and is found only in its compounds in the oxidation stage of + 2. In the electrochemical potential series Zn can be considered as being rather unnoble metal. For this reason zinc reacts with acids liberating hydrogen. Zinc solves also in alkaline solutions producing ZnO_2^{2-} -ion and liberating hydrogen.

The chemical composition of the concrete varies greatly depending on what extent the component materials such as cement, aggregate, water and chemical admixtures are used for making the concrete.

In the hardened concrete both hydrated and unhydrated clinker minerals are at present depending on the type of binding agent and on the degree of hydration.

The composition and quality of the water in green and hardened concrete depends mainly on the type of the cement used and partly on the mixing water. The fact is that the extract of concrete and cement is alkaline and normally the whole concrete environment is alkaline.

The alkality is depending on the high concentration of the hydroxyl ions. Thus zinc as a not-noble metal reacts quite vigorously in green concrete forming hydrogen. Since Finnish Portland cements have normally a high alkali content, the pH of their extracts can be higher and the reaction between concrete and zinc is obiously more vigorous.

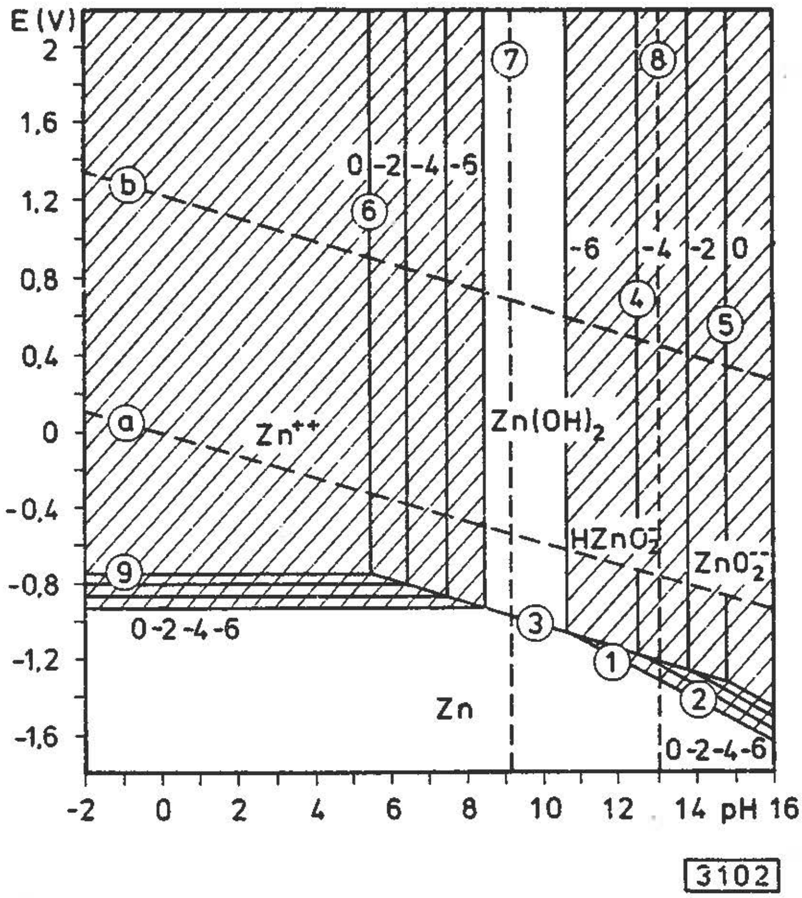
As shown in a diagram of Figure 1 introduced by Pourbaix /7/ Zn $(OH)_2$ is stable in the pH area 8-11. The solubility of zinchydroxide in the cement paste at this pH area is about 10^{-3} - 10^{-4} moles/l. Investigations carried out, have, however, shown that zinc is passive up to the pH value of 12.5, that is why the corrosion resistance of zinc is better than what one can expect from it. When zinc reacts in the extract of cement and concrete the following reactions have been introduced:

$$Zn + 2H_2O \rightleftharpoons Zn(OH)_2 + H_2 \uparrow$$

$$Zn(OH)_2 + NaOH \rightleftharpoons [Zn(OH)_3]\ Na$$

$$2Zn + Ca(OH)_2 + 6H_2O \rightleftharpoons Ca\ [Zn(OH)_3]_2 \cdot 2H_2O + H_2 \uparrow$$

Thus both in the alkaline and calciumhydroxide environments complex combounds of zinc and alkali and calcium metals and hydrogen are being formed.



1. Zn + 3OH$^-$ ⇌ HZnO$_2^-$ + H$_2$O + 2e$^-$ E_h = 0,054 + 0,088 pH + 0,0295 log(HZnO$_2^-$)^2
2. Zn + 4OH$^-$ ⇌ ZnO$_2^-$ + 2H$_2$= + 2e$^-$ E_h = 0,441 - 0,118 pH + 0,0295 log(ZnO$_2^{2-}$)
3. Zn + (OH) ⇌ Zn(OH)$_2$ + 2e$^-$ E_h = 0,439 - 0,059 pH
4. Zn(OH)$_2$ + OH$^-$ ⇌ HZnO$_2^-$ + H$_2$O log(HZnO$_2^-$) = 16,68 + pH
5. Zn(OH)$_2$ + 2OH$^-$ ⇌ ZnO$_2^{2-}$+ 2H$_2$O log(ZnO$_2^{2-}$) = 29,78 + 2 pH
6. Zn(OH)$_2$ + 2H$^+$ ⇌ Zn^{2+} + 2H$_2$O log(Zn^{2+}) = 10,96 - 2 pH
7. Zn^{2+} + 2H$_2$O ⇌HZnO$_2^-$ + 3H$^+$ $\log \frac{(HZnO_2^-)}{(Zn^{2+})} = 27,63 + 3\ pH$
8. HznO$_2^-$ ⇌ ZnO$_2^{2-}$ + H$^+$ $\log \frac{(ZnO_2^{2-})}{(HZnO_2^{2-})} = 13,11 + pH$
9. Zn ⇌ Zn^{2+} + 2e$^-$ E_h =-0,763 + 0,0295 log(Zn^{2+})

Figure 1. pH-potential-diagram of zinc introduced by Pourbaix /7/.

3.1.2 Prevention of reactions

The possibility of preventing the reactions were studied by means of a chromating treatment.

In the tests, it was observed that different treatments differed greatly from each other. Particularly with the weak solutions the concentration, acidity and immersion time had an effect on the final outcome.

The specimens treated with $K_2Cr_2O_7$ + a weak acid solution had no retarding effect on hydrogen generation or vice versa. On the other hand the $K_2Cr_2O_7$-water solution clearly weakened hydrogen generation and will obviously decisively improve the bond between the zinc-coated steel and the concrete. The tests indicated, however, that the chromate solution must be sufficiently strong in order to achieve a positive result. In the treatment with a 2.5 per cent chromate solution the gas generation can be regarded as being prevented when visually examined. In this case it was no longer observed that the temperature of the solution or the immersion time had any distinct effect on hydrogen generation. On the other hand in the case of weaker solutions the immersion time had a distrinct effect: the longer the zinc-coated bars were in an immersion solution, the better the outcome when the concentration of the treatment solution is below the fixed concentration limit.

Mixing dichromate and mix water to achieve a 500 ppm concentration as advised in the instructions, had not a sufficiently favourable effect, on the contrary hydrogen generation was abundant.

On the basis of the tests the chromate treatment in continued investigations was employed using a 1.5 per cent $K_2Cr_2O_7$-solution and a one-minute immersion time. Subsequently, the bars were washed with cold water. The temperature of the solution was of no significance, but it is, however, advisable to keep the solution warm at a temperature not less than 20^oC during the treatment to ensure the successful end /10/.

3.2 Mechanical interaction

3.2.1 Introduction

For its behaviour the reinforced concrete can be regarded as being a composite material. The necessary qualification for its efficient behaviour is, however, the best possible interaction between concrete and reinforcement. The best possible interaction thus limits, for example the size of the slip between these two materials, so that the stresses can be transferred from one material to the other through the boundary surface. The better the interaction properties of these materials, the firmer is also the boundary surface in general. On the other hand, if the boundary surface weakens, the interaction properties also grow weaker.

When the zinc-coated bars are placed in concrete there occur on the boundary surface chemical reactions of various stages depending on each case, which can weaken the strength of the joint. Consequently it is obvious that the mechanical interaction between the concrete and the reinforcement declines. It is, however, possible to passivate chemical reactions or even prevent them completely, in which case no drawbacks occur.

3.2.2 Interaction mechanism

The interaction mechanism of the zinc-coated and uncoated deformed bars is in principle similar to each other.

The interaction between the deformed bar and the concrete at various stages of its behaviour is in the first place influenced by

- adhesion
- friction and
- mechanical interaction.

The significance of adhesion or bond is greatest at a low loading level, in which case the slip has not yet occurred.

When strain is increasing the friction at the next functional stage has the greatest effect. The surface of the bar can never be completely smooth, when the bar begins to slip cement stone cuts along the surface composed of the outermost parts of the bar. Only after the beginning of this slip the friction has actually a predominat effect. After the bar has slipped further as slip barriers and transfer more and more force towards the slip unit. The behaviour of the bar hereafter depends mainly on the type of the surface pattern of the bar. The interaction is generally considered to discontinue when the tension force of the bar is beginning to decrease, even if still loaded. The interaction of the deformed bars discontinues usually either in a corresponding way as at the initial stage of the friction or when the concrete dowel between the ribs of the bar cuts into the concrete along the surface composed of the outermost parts of the bar or when the concrete is crushed as a wedge-like front facing the edges.

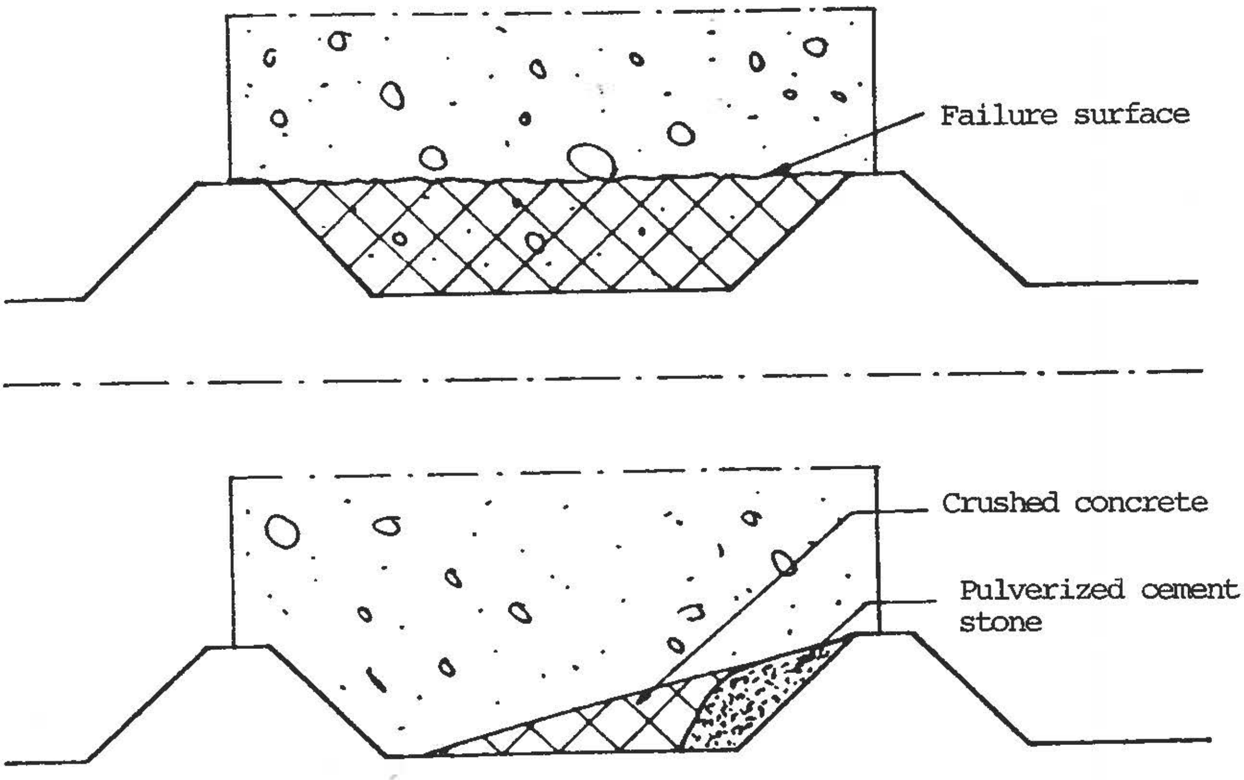


Fig 2 . Failure states of the interaction between the deformed bar and the concrete in standard concrete with single rib spacing /3/.

The behaviour of the zinc-coated deformed bars is identical in corresponding conditions, if zinc has not been chemically active in concrete. If zinc has reacted chemically in concrete hydrogen pores have been formed on the boundary surface of the bar and the concrete.

Depending on the amount and size of hydrogen pores different factors can be of greater or lesser importance but it seems obvious that adhesion has lost some of its importance if there has been abundant generation of hydrogen pores.

Similarly, the friction stage grows less important. If the surface is very active, the interaction of plain zinc-coated bars on concrete is weak. The deformed bars act almost entirely by means of mechanical interaction between the ribs of bars and the concrete. After the concrete loses some of its strength the slips on the boundary surface are great and the bond capacity remains less high, even if failure occurs in either one or the other way.

Hot-dip galvanized reinforcing steels have been used more than 60 years, and their earliest bond research results are almost of the same age. When examining the results concerning the interaction between the bars and the concrete the incompatibility of the obtained results is distinctly noticeable, which for its part has restricted application areas of zinc-coated reinforcement.

Conclusions drawn by some researchers have been collected in Table 2 showing the contradiction which has existed through ages. It has to be mentioned that all these research reports do not give information of the zinc-coating method, apart from the fact that there is no mention made of the surface passivation treatment of the bar or of the composition of cement or of the soluble chrome content in it /10/.

Table 2. Research results concerning the bond of zinc-coated bars.

Researcher or publication		Year	Bar type	Effect of zinc-coating on bond
Slater & al.	/2/	1920	plain rib	weakens
Schmeer	/2/	1920	plain	improves
Brodbeck	/2/	1954	plain	improves
Robinson	/2/	1956	plain (rusty)	weakens
French research	/2/	1959	plain (rusty) plain (pure)	the same improves
Bird	/2/	1962	prestressing wire	weakens
Bresler, Cornet	/1/	1964	plain rib	the same or improves
Gukild, Hofsoy	/2/	1965	rib	weakens
English research	/13/	1969	plain rib	weakens weakens
Soretz	/11/	1971	rib	weakens
Maissen	/6/	1976	plain rib	weakens the same or weakens
Roberts	/9/	1978	plain rib	the same or improves the same or improves

Based on today's knowledge it is possible to estimate that these very factors have contributed to the incompatibility of the results. Apparently, the activity of the surface of the bar with the concrete has thus changed depending on the chromate content of the used cements. Furthermore, the pureness of zinc on the bar has probably varied, too.

3.2.3 Results of bond tests

Variations in surface treatment of test bars are given in Table 3.

Table 3. Surface variations of test bars

	Charge no.	Hot-dip galvanizing chromating 1)	Hot-dip galvanizing no-chromating	Sprayed zinc-coated chromating 1)	Sprayed zinc-coated no-chromating	Not zinc-coated
No pre-treatment	I	-	-	-	-	+
	II	-	-	-	-	-
Sand-blasting	I	+	+	+	+	-
	II	+	-	+	-	-
Shot-pinned galvanizing	I	-	-	+	-	-
	II	-	-	+	-	-

\+ means that the treatment has been carried oyt
\- means that the treatment has not been carried out

1) Chromating treatments of bars differed from each other in charges I and II.

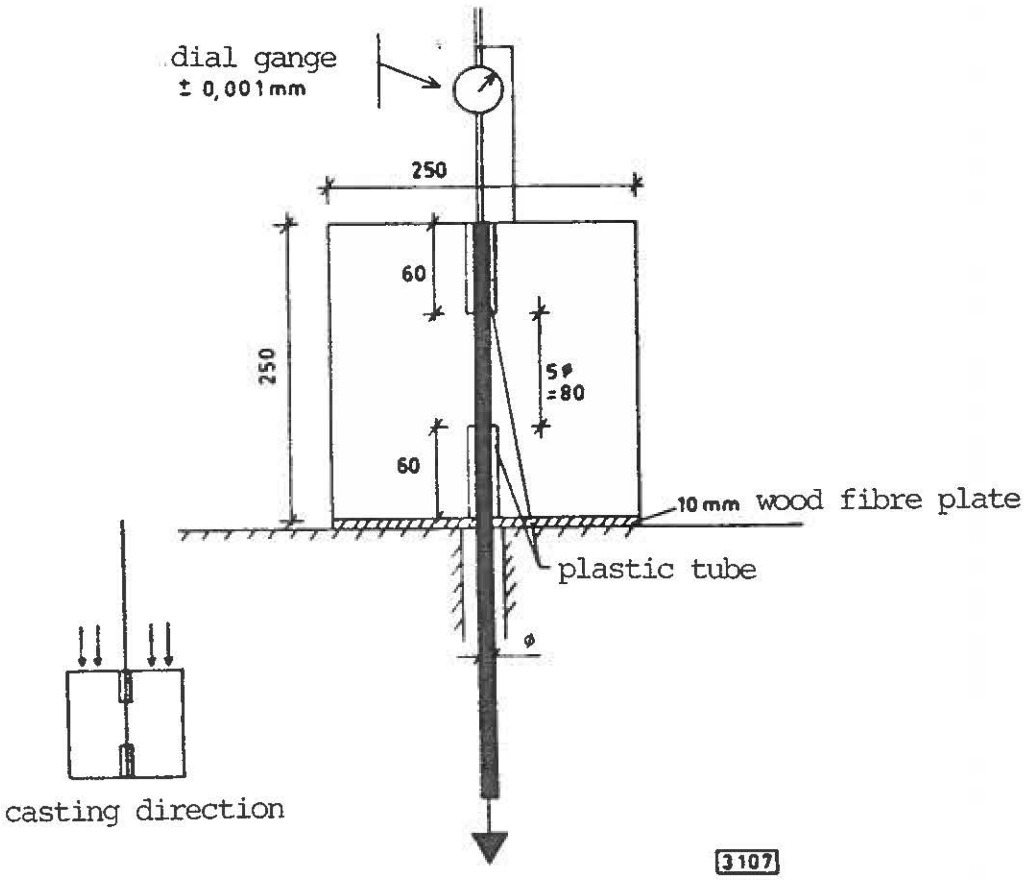


Fig 3. Schematic illustration of bond test arrangements.

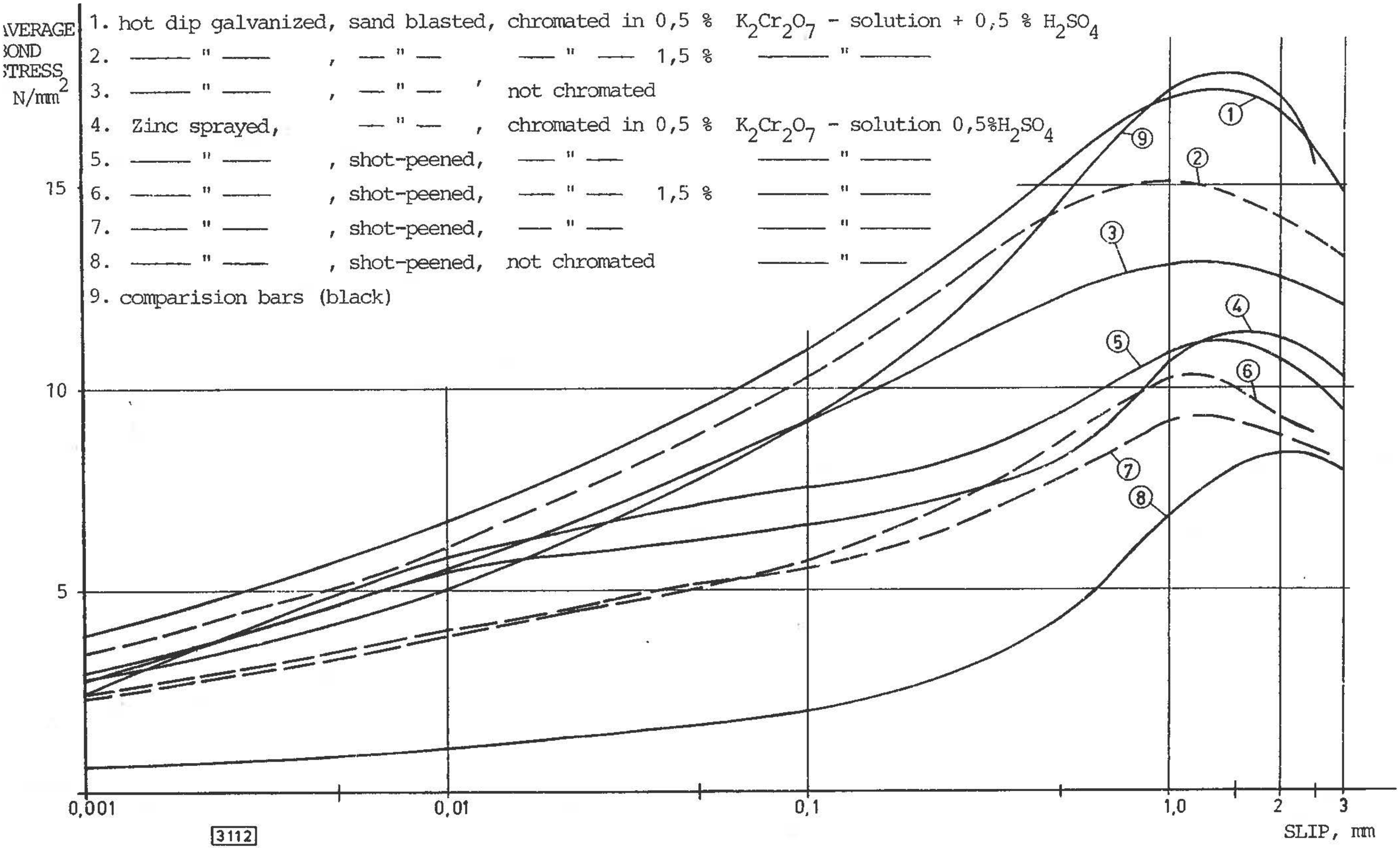


Fig 4. Average bond slip curves of pull-out tests /10/.

On the basis of the test results the following conclusions, from the effect of different chromating treatments and surface treatments on bond properties of the deformed bars, can be drawn /10/

- Zinc-coated bars should be passivated before concreting using e.g. chromating.
- Alternitively to chromating passivating can be done by storing the bars in air for about a month where by the zinc is passivated due to oxygen.
- The bond coefficient of zinc-sprayed passivated bar should be decreased by 40 %.
- Hot-dip galvanized passivated bar is approximately equal to black untreated deformed bar in bond.
- The bond coefficient of hot-dip galvanized bar without passivating treatment should be reduced by about 20 %.
- There is no defference in bond between the sand-blasted surface and shot-peened zinc-sprayed and passivated surface.
- Chromating treatment can be carried out as follows: immersion in not less than a 1.5 per cent $K_2Cr_2O_7$-solution of 20°C for about 1 minute and subsequent washing of the bars with water. A stronger solution (e.g. 2.5 per cent solution) will give still safer protection against passivation.

3.3 Durability

3.3.1 General

On the basis of the test results and experience gained in practice it can be established that zinc coating protects reinforcements from corrosion very well in the structures exposed to moisture or water. Such structures are, for example, the bridges and piers in fresh water environments, the balconies, the external walls of buildings and the majority of the farm house interiors. Thin prefabricated structures are also suitable for applications. In applications, such as the edge beams of highway bridges, the concrete structures manufactured by using chloride containing aggregates, the hydraulic structures of the chemical industry, zinc coating delays the beginning of corrosion and retards the corrosion process considerably, but it is not known for certain whether zinc coating in more severe conditions can prevent corrosion completely. The results from the experiments made on the structures under conditions like these indicate that their durability has been very good at intervals of 10 to 30 years when compared with the uncoated deformed bars of the same structures that have corroded badly even in a few years. On the other hand, the results of laboratory tests have varied considerably. The advantages of the zinc-coated reinforcements to the full even in surroundings containing lots of salts are probable but they can be ensured only when more experience has been gained in practice, for example in Dutch marine structures.

3.3.2 Zinced bars in air

In conjunction with this research bending tests on zinc-coated bars were performed to evaluate the durability of coating when bending the bars.

It was then established that if cracks are developing in the zinc layer, the larger they are, the smaller the bending radius of the bar. Furthermore it could be noticed that when using the smallest permissible bending radius of stirrups either type of coating investigated does not hold out without cracking. On the other hand, the main bars can be bent using permissible bending radii without the risk that the zinc layer will crack.

To prove the corrosion sensitivity of these bent bars at their cracking points the bars were stored for almost a year in the relative humidity, RH 100 %, and at the temperature of 20°C. Besides, uncoated black bars were added to storage as comparison test specimens.

When the zinc-coated test specimens were visually examined no traces of the corrosion products of iron could be seem at the cracks developed in bending. On the other hand there was on black comparison test bars a considerable amount of loose rust and local corrosion pits.

In the case of zinc-coated bars a zinc-oxide formation of highter colour than the zinc-coated surface appeared at the cracks, which closed the crack in the zinc layer and thus prevented corrosion localized in steels. The zinc-oxide formation had developed similarly in the case of hot-dip galvanized and spray galvanized bars.

Figs. 4...6 show some bent bars, in the zinc layer of which cracks can be seen clearly, as well as the corresponding bars and the comparison bar after a 1.5-year fog curing /10/.

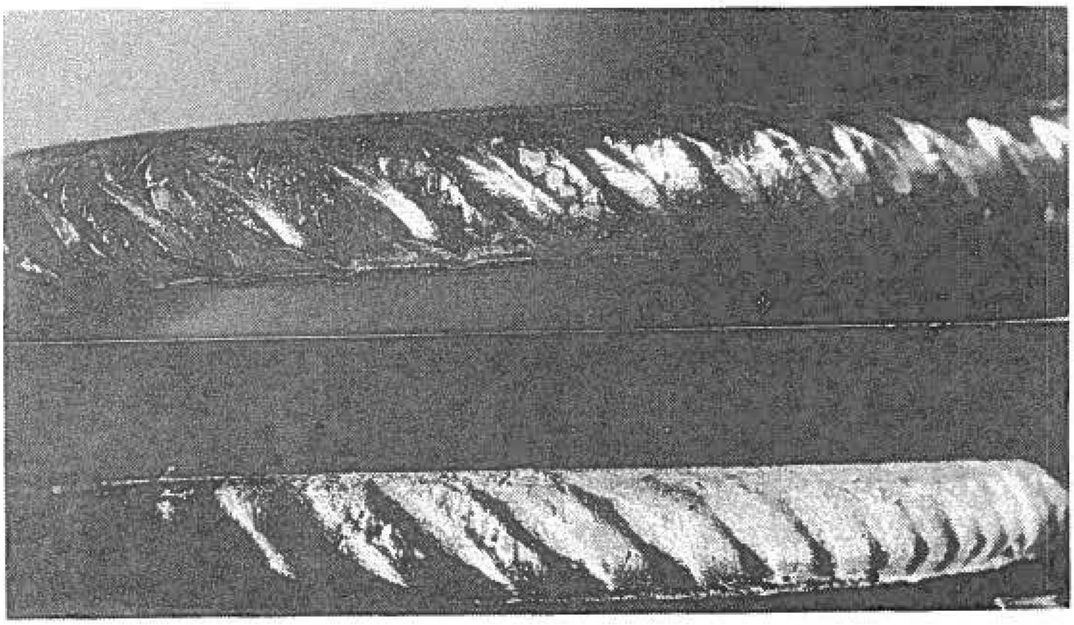


Fig. 4. Hot-dip galvanized ∅ 8 deformed bar, bending radius 24 mm, bending angle 135°
- upper bar: after bending
- lower bar: after a 1.5-year air storage

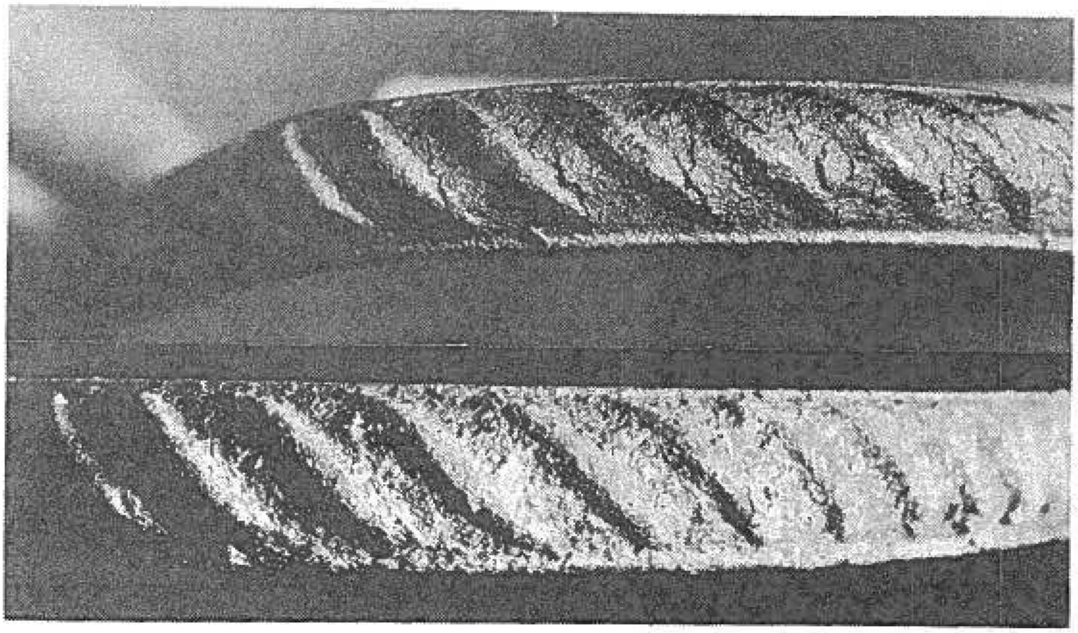


Fig. 5. Zinc sprayed ø 8 deformed bar, bending radius 24 mm, bending angle 135°
- upper bar: after bending
- lower bar: after a 1.5-year air storage

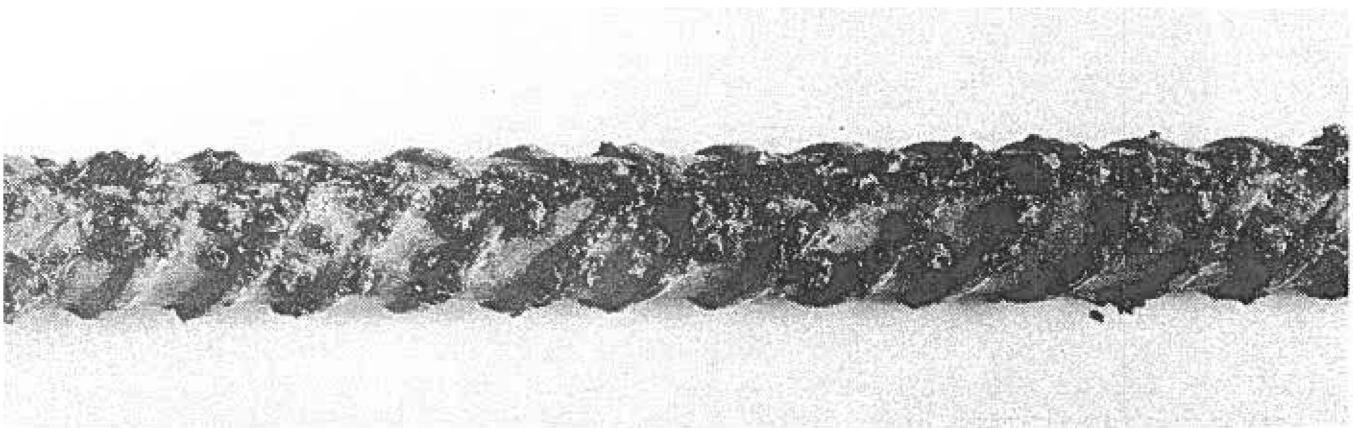


Fig. 6. Uncoated bar after 1.5 years' air storage

3.3.3 Bars in cracked concrete

Test specimens were the cylinders of ∅ 44 x h 150 mm with one ∅ 8 mm bar in the middle of each cylinder. They were stored in different liquids: drinking water, Baltic Sea water and North Sea water. North Sea water (In one litre water: 28 g NaCl, 7 g $MgSO_4 \cdot 7 H_2O$, Sg$MgCl_2 \cdot 6 H_2O$, 2 MgCaCl· 6 H_2O ja 0,2 g $NaHCO_3$).

3.3.3.1 Uncoated bars

The duration of the test on the specimens of this quality was 1.5 years. During this time the specimens stored in drinking water only remained without rusting. The steel of this quality behaved most poorly in sea water conditions, even though rusting started in Baltic Sea water almost equally fast but not quite so effectively. The fact that the bars rusted in RH 100 %, but not correspondingly in water may indicate that the concrete is neutralized at the crack extending to steel and the protective alkalinity disappears from a small region. On the other hand, when the concrete is exposed to air there is no dissolving water which would move the rust through the crack.

3.3.3.2 Zinc-sprayed bars

In the case of zinc-sprayed bars the amount of corrosion product of zinc was great in the underwater region and above all in the areas close to the crack. The beginning of slight rusting could be seen in the specimens at the age of 1 year and 4 months when stored in sea water. Entirely unexpected was their behaviour in RH 100 %, during which time small amounts of rust appeared on the surface of zinc-coated steels.

Figs. 7 and 8 illustrate two test specimens that have been in sea water for 8 months. Fig. 7 shows clearly how the white corrosion product of zinc concentrates at crack and how it is being carried along into concrete. Again it can be seen from Fig. 8 that the cracked surface and partly the bond surface of steel has been nautralized as a result of the Zn corrosion product.

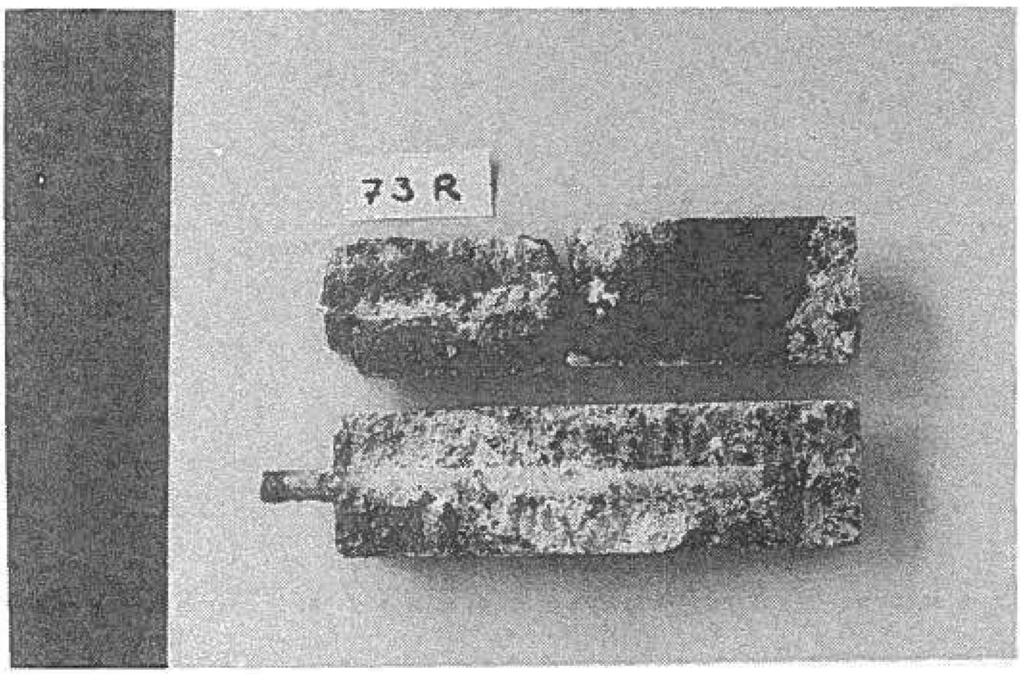


Fig. 7. Corrosion test specimen stored for 8 months in sea water after the splitting of the specimen.

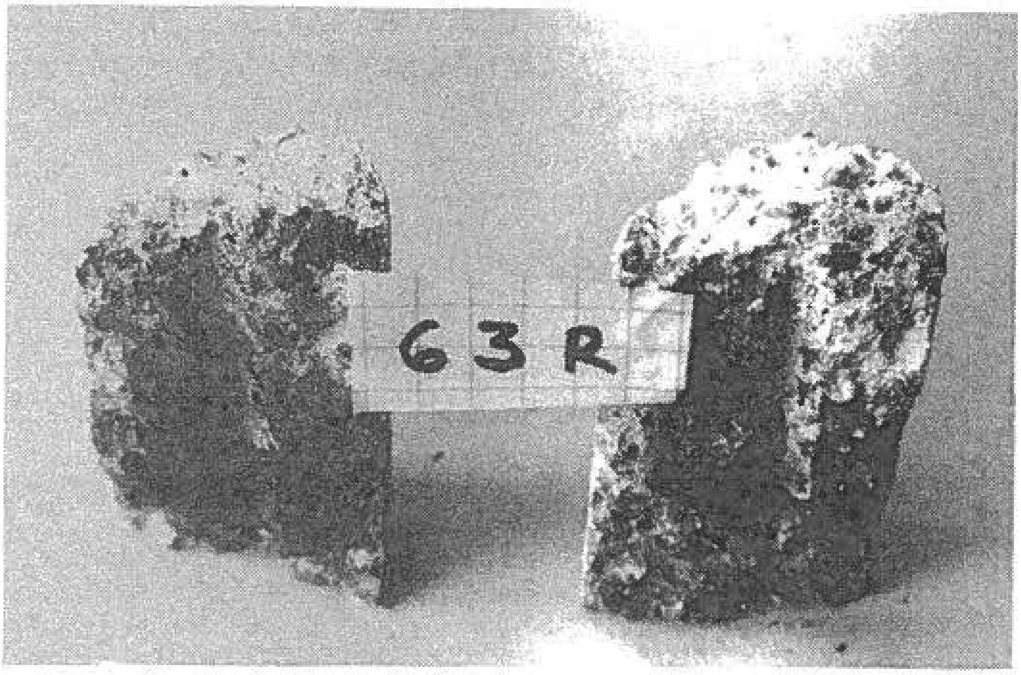


Fig. 8. Test specimen stored for 8 months in sea water. The bond and crack surface neutralized pH < 10.

3.3.3.3 Hot-dip galvanized bars

The hot-dip galvanized steels in a eight-month test seemed first behave in the best way in all conditions in sea and soft water too. Later, however, the hot-dip galvanized steels rusted but not to such a degree as the uncoated steels.

The hot-dip galvanized steels behaved quite well in RH 100 % and in water.

3.4 Durability tests of zinc-coated reinforcement in chloride containing environment when subjected to repeated tensile stress

3.4.1 Purpose of the tests

The purpose of the tests was to elucidate the durability of the Finnish deformed bars zinc-coated and surface-treated by different means in a reinforced concrete beam subjected to repeated flexural moment, which in the split state are immersed halfway in chloride containing water.

The purpose of the cracks and the cloride content was to intensify corrosion in bars. The differences in the corrosion rate were confirmed with the fatigue tests on the tension bars of the beams carried out after two thousand loading cycles and after the test, the duration of which was one year and half.

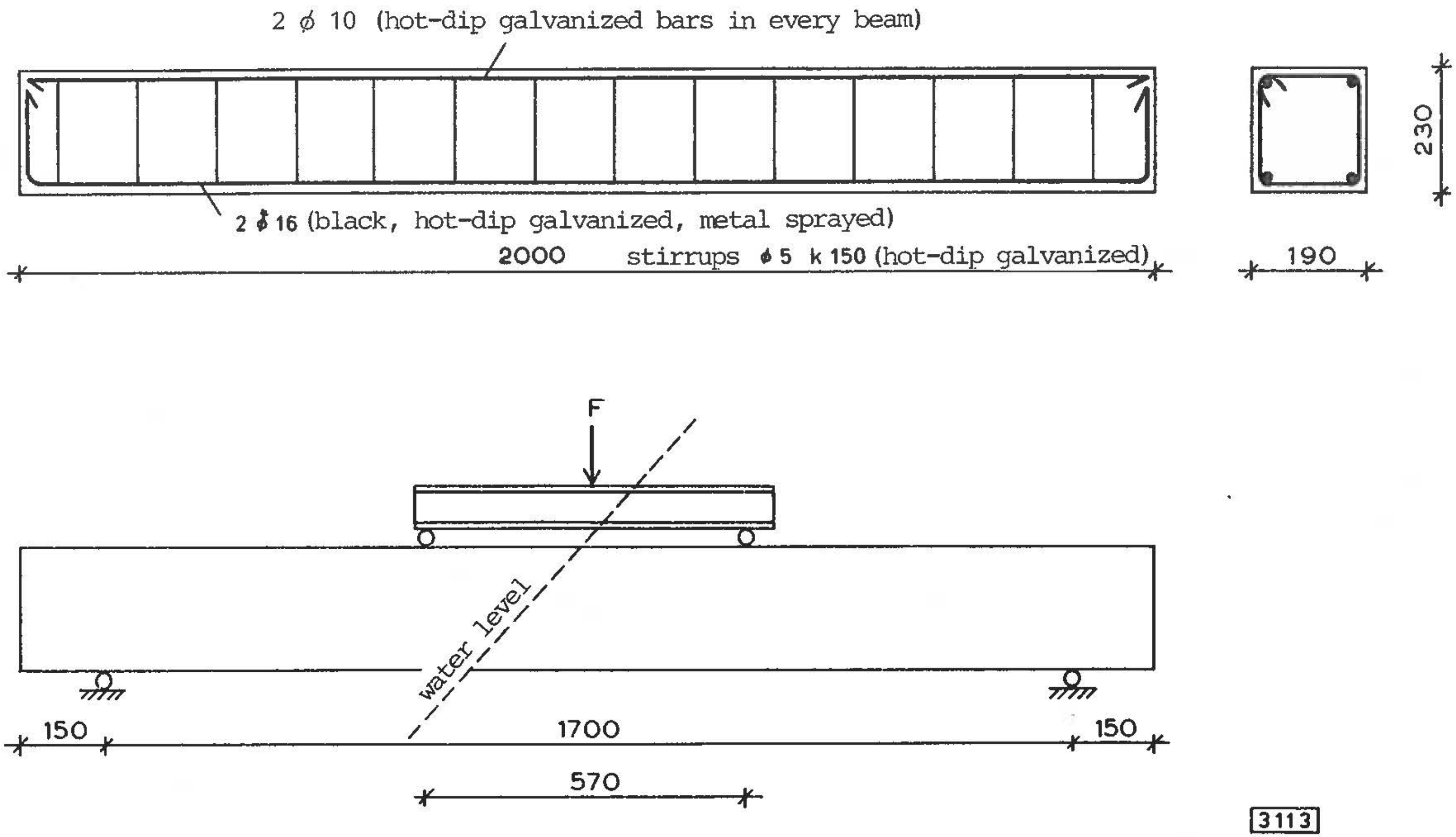


Fig. 9. Test specimens and loading arrangements.

3.4.2 Testing following the corrosion test

After the corrosion loading test the tension bars were detached from two beams of each type. The bars were removed from the beams with the greatest care without scratching the bars. Simultaneously with this the diagrams of the cracks in beams were plotted. The test specimens for fatigue tests were cut almost symmetrically from the middle of each reinforcing bar.

There were no traces of corrosion visible in any test bar when visually examined. Other investigations which would map traces left by corrosion were not carried out because, on the basis of fatigue tests made, there was no reason for them. A part of the test beams will be submitted for some years more to this test to verify still longer time behaviour of the reinforcement.

On the basis of test results it was stated that the fatigue strengths of the untreated bars and the bars coated by various means after the corrosion test were approximately identical with those of the bars without corrosion protection treatment. Thus it was not proved that the corrosion effects of the salt solution produce variations in the fatigue strength of the reinforcement of the beams that have been immersed halfway in a salt solution, stored for 1.5 years in the split state and subjected to repeated load /10/.

4. POSSIBLE USE OF ZINC-COATED REINFORCEMENT

4.1 General applicability

The zinc-coated reinforcements have the advantage of having essentially longer service life in the structures than the untreated reinforcement in such conditions in which the zinc coating protects the reinforcement from corrosion. It has to be noted that the protective effect of zinc coating is not an absolute necessity, provided that it prolongs the service life of the structure and reduces the need of repair to such an extent that the current value of money thus being saved up is higher than the costs induced by zinc coating. An advantage is often also an improved appearance, when the concrete surface is prevented from getting dirty as a result of rusting of reinforcement, and splitting of the surface is prevented too. Sometimes it might be an advantage that the weight of the structure decreases due to a reduction in the thickness of the zinc-coated protective concrete layer.

4.2 Suitability of applications

In the structures, such as bridges and piers under soft water conditions, balconies, external walls and farm production buildings, which are exposed to moisture and water in ample measure zinc coating protects very well the reinforcement from rusting at the cracks in concrete and local corrosion pits, and ensures a long service life of the structure.

When using blended cements the pH of concrete reduced, in which case the risk that zincates are formed is lessened and the advantages of zinc coating increase in comparison with the concrete made of Portland cement.

Thin prefabricated structures are especially suitable for application purposes. In most severe conditions it might be found necessary to use additional protection for very important fixings outside the concrete in addition to zinc coating, for example paint application or by replacing them with the fixings made of stainless steel.

In the structures to which a very strong chloride effect is directed zinc coating delays the beginning of corrosion and retards corrosion considerably. Such structures are, for example, the edge beams of highway bridges, the structures manufactured by using chloride containing aggregates or admixtures, the oil drilling and pumping structures in the marine environments and certain industrial structures. The service life of the structure is thus prolonged significantly but zinc coating does not prevent corrosion completely. The advantages of using zinc coating under these conditions cannot be judged until more experience has been gained, e.g. in Dutch marine structures.

The protective effect of zinc coating on the corrosion of reinforcement is weak when coating comes into contact with substances that dissolve zinc well or react easily with zinc. Such substances are alkalis and acids, although in a alkaline solution a thin passive layer is formed on the surface of zinc. Against these substances other coatings, suitable for protection purposes, must be used.

4.3 Examples of applications for which zinc coated reinforcement so far have been used

In Western Europe, the portion of the hot-dip galvanized reinforcements is on an average around 1 % of all reinforcements used in reinforced concrete structures. In the United States of America the portion of zinc-coated reinforcements is 2.1 % of all concrete reinforcements. In Sweden, the corresponding portion is 0.3 %. In Finland an inconsiderable portion of these reinforcements has been used.

According to the Dutch estimation by A.L. van Veen, the most economical portion of zinc-coated reinforcements would be around 5 % of all reinforcements used. The need to use these reinforcements is apparently far greater in Holland due to the great number of marine structures built there than the average use in other parts of Europe.

Examples of applications for which the hot-dip galvanized reinforcements have been used and experience gained in using them:

- The bridges of Bermuda Islands, which are exposed to chlorides originating from concrete aggregates, water of the Atlantic and salty air. The oldest bridges are about 30 years old and there are no signs of corrosion damage in the samples taken from zinc-coated reinforcements. The untreated reinforcements in the same conditions have corroded very badly in a few years.
- In the USA, hot-dip galvanized reinforcements have been used in almost three hundred bridges.
- Hot-dip galvanized steels have been used as reinforcements of prefabricated wall units, e.g. in USA, Great Britain, Australia and in Norway in the 1960's and 1970's.
- In marine structures, such as piers, dams, oil drilling rigs and lighthouses, use has been made of hot-dip galvanized reinforcements, for example in Japan and the Netherlands.

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