CORROSION OF BONDED ANCHORS IN CONCRETE

KORROSION VON VERBUNDDÜBELN IN BETON

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ABSTRACT

For post installed reinforcement connections or bonded anchors different injection mortars are often used. In general, the polymer-based injection mortar systems are classified as very good in literature due to their properties, especially with regard to the permeability of water or harmful substances. The behaviour of a post installed rebar is also investigated in corrosion tests, if the system is to be evaluated for a European Technical Approval. The corresponding regulations are summarised in EOTA TR023 [6].

The purpose of the presented investigations is to investigate the corrosion protection effect of five different injection systems and to investigate the cause of corrosion if steel corrosion was observed. All polymer based injection systems showed initiation of steel corrosion during the 24 weeks of (outside) storage. Only the mortar with mineral binder showed no corrosion during the tests carried out as part of the project. However, the investigations of pore distribution and water absorption in mortar have confirmed the non-permeability to water and water-based salt solutions. Thus, the cause is to be found in existing weak points and air bubbles in the mortar. More detailed descriptions of the investigations carried out are summarised in [1].

ZUSAMMENFASSUNG

Für nachträglich installierte Bewehrungsanschlüsse oder Verbunddübel werden häufig unterschiedliche Injektionsmörtelsysteme verwendet. Die meist kunststoffbasierten Injektionsmörtelsysteme werden in der Literatur aufgrund ihrer Eigenschaften, vor allem bezüglich der Durchlässigkeit von Wasser oder Schadstoffen, als sehr gut eingestuft. Das Verhalten eines eingemörtelten Bewehrungsstabs wird auch bei Korrosionsversuchen untersucht, wenn das System für eine europäisch technische Bewertung beurteilt werden soll. Die entsprechenden Vorschriften sind in EOTA TR023 [6] zusammengefasst.

Ziel der Untersuchungen ist es, die Korrosionsschutzwirkung von fünf unterschiedlichen Injektionssystemen zu untersuchen und im Fall von auftretender Stahlkorrosion, die Ursache zu untersuchen. Während den 24 Wochen der Auslagerung haben alle kunststoffbasierten Injektionssysteme eine beginnende Stahlkorrosion aufgezeigt. Lediglich der Mörtel mit mineralischem Bindemittel zeigte im Rahmen der hier durchgeführten Versuche keine Korrosion. Die Untersuchungen der Porenverteilung und der Wasseraufnahme bei Mörtel haben jedoch die Undurchlässigkeit gegenüber Wasser und wässrigen Salzlösungen bestätigt. Somit ist die Ursache, bei vorhandenen Schwachstellen und Luftblasen im Mörtel zu suchen. Detaillierte Beschreibungen der durchgeführten Untersuchungen sind in [1] zusammengefasst.

KEYWORDS: Polymer-based injection mortars, corrosion, bonded anchors, chlorides, infiltration behaviour, aqueous salt solution, cracked concrete

1. PREFACE

Despite the very good properties of injection mortar, especially its permeability to water and aqueous salt solutions, corrosion damage occurs time and again. In order to investigate the causes of corrosion, threaded rods were installed in special test specimens (concrete blocks with crack) using 5 different injection mortars. The specimens were exposed to artificial seawater for 24 weeks. The artificial seawater was prepared according to DIN 50905-4 [2]. The following tests were carried out on these test specimens:

- Storage tests of the test specimens in artificial seawater
- Pore distribution of the mortar used according to DIN ISO 15901-1 [3].
- Water absorption of the mortars used according to DIN EN 1936 [4].
- Water absorption coefficient of the mortar used according to DIN EN 1925 [5].
- Measurement of chlorides on the threaded rod

The mortars used are:

- Fixing cement made from a mixture of Portland cement and alumina cement,
- Injection mortar made of 2-component resin,
- Polyester based injection mortar,

- Epoxy based injection mortar and
- Vinylester-based injection mortar.

For each mortar type, three specimens (cubes) were examined (for corrosion) after 2 weeks, 6 weeks & 12 weeks, and one specimen after 18 weeks.

2. SPECIMEN AND TEST PROCEDURE

The test specimens are concrete cubes with an edge length of 15 cm and a strength class of C20/25. All the concrete cubes were casted from the same batch of concrete. For the tests, the cubes were sawn into 2 halves and then clamped together again. This simulates a crack in the cube through which water can penetrate into the interior of the component.

To determine the water absorption coefficient and the water absorption, the concrete test specimens are sawn to an edge length of approx. 3 cm and polished on both sides.

The threaded rods used are standard 4.8 grade threaded rods according to DIN 976-1, with metric ISO standard thread and uncoated surface. The threaded rods are made of carbon steel. The diameter of the threaded rods was M12. The rods were cut to a length of 14 cm and thoroughly cleaned with benzyl alcohol and ultrasound before installation. This enables the subsequent assessment of the surface in which corrosion occurs, to be performed.

To produce the test specimens, the cube halves were first clamped together with cable ties. Then a 70 mm deep hole with a diameter of 14 mm was drilled centrally in the cube in such a way that both cube halves were drilled almost identically.

The installation procedure was carried out according to the manufacturer's specifications. The drill holes were cleaned and then the respective mortar was injected. The threaded rod was inserted with rotating movements and the curing time was waited. A total of 60 specimens (cubes) were produced and were stored in artificial seawater in groups of 10 cubes per storage tank. The water level was adjusted so that it only reached the upper edge of the specimen. The reason for this is that no water flows over the upper edge of the concrete cube and therefore the penetration of the chlorides can only take place through the concrete & the crack and not through the mouth of the borehole.

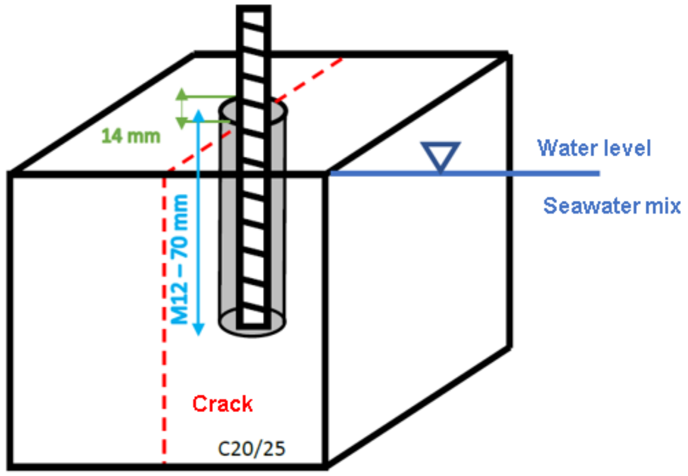

Fig. 1: Experimental set-up and test specimens for corrosion tests on mortar-grouted threaded rods in cracked concrete C20/25

After removing the specimens from the storage tank, they were split and the threaded rods were removed. All steps were documented photographically. In addition, the pH value of the test liquid was checked and its development observed during each removal. The threaded rods were then visually assessed for steel corrosion.

For the purpose of visual assessment, the threaded rods were removed from the concrete test specimen and examined more closely. Three threaded rods per mortar type were considered at each time of removal and the results were averaged. The following areas were assessed separately:

- Transition section: Thread section between atmosphere and mortar
- Threaded section: Thread section which is completely covered with mortar.
- End surface: Surface which rests on the concrete body at the bottom of the borehole.

The extent of steel corrosion on the surface of the threaded rods is rated under four categories, viz., no steel corrosion, low steel corrosion (< 10%), strong steel corrosion (≥ 10% to < 100%) and complete steel corrosion (100%).

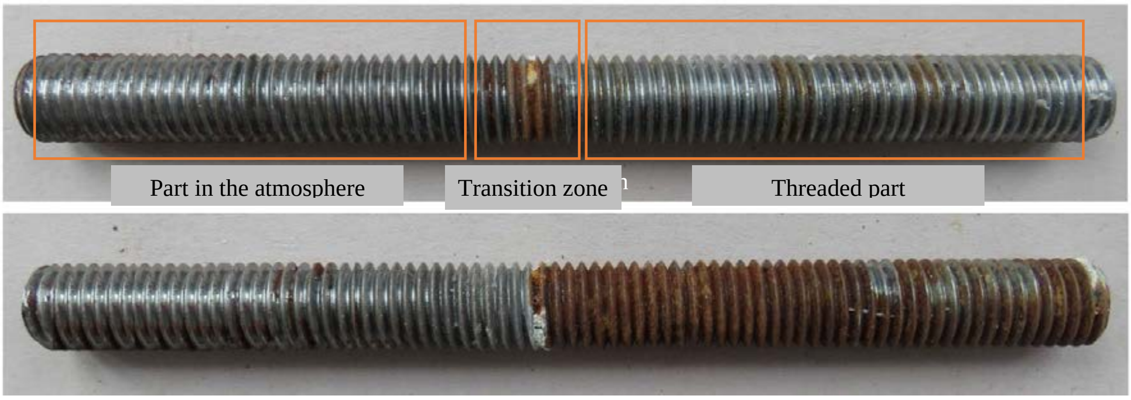

Fig. 2: Example for the visual assessment of the threaded rods (injection mortar made of 2-component resin) in the case of an offshore storage after 2 weeks (top) and 18 weeks (bottom) in artificial seawater

The test results are summarized and presented in detail in the following section.

3. TEST RESULTS

The pH value of the artificial seawater was determined at the time of each sampling. According to the measurements, pH did not change over the course of 24 weeks and was between 8.4 - 9.3.

In the area of transition of the threaded rod, with the exception of the fixing concrete mortar, a moderate to strong red corrosion was observed in all cases. The reason for this is presumably the proximity to the water surface and the associated high humidity in the storage tanks. If the mortar has not completely sealed the borehole in this transition area, there will be strong or complete steel corrosion in this section.

At the end surface of the threaded rods no clear result could be achieved. It can be assumed that the corrosion of the end surface depends strongly on the installation of the mortar. If there is no mortar at the end of the borehole while the threaded rod is being screwed in, the threaded rod will not be protected against the concrete and will be corroded even more rapidly.

Table 1 summarizes the evaluation of steel corrosion for the threaded area. Injection mortars made of 2-component resin and epoxy resin show up to 10% steel corrosion after only two weeks.

In the case of mineral mortar and injection mortar based on polyester or vinyl ester, no steel corrosion was detected after 2 weeks of exposure. However, after 24 weeks of exposure, all mortar types, with the exception of mineral mortar, show more or less strong steel corrosion ($\geq$ 10% to < 100%).

Table 1: Visual assessment of corrosion in the threaded area for the different mortar types investigated when exposed to artificial seawater

Time of exposure	Fix-Cement	2k resin	Epoxy resin	Polyester resin	Vinylester resin
2 Wochen					
6 Wochen					
12 Wochen					
18 Wochen					
24 Wochen					

No steel corrosion	Steel corrosion < 10%	Steel corrosion ≥ 10% and < 100%	Steel corrosion 100%

The mineral mortar consists of Portland cement and has a preventive effect against chlorides due to the alkaline reaction. Due to the higher pH value in the area of the thread, the steel is passive and steel corrosion is inhibited. It can be assumed that this is the reason for the good corrosion resistance of the mineral mortar. Polymer-based mortars do not have an increased pH value and cannot bind chlorides. The protective effect of these mortars is therefore based exclusively on "impermeability".

The investigations show very clearly that the steel corrosion only occurs in patches and is restricted locally. This can be shown very clearly in Fig. 3.

Fig. 3: Examples for the visual assessment of the threaded rods (vinyl ester based injection mortar) after 2 weeks (top) and 18 weeks (bottom) in artificial seawater

This observation suggests that chlorides could only penetrate at localized points and that the mortar had no protective effect in these areas.

Besides the steel corrosion further observations were made. After separating the two halves of the cube, the condition of the hardened mortar was examined more closely.

Fig. 4 shows a difference in the condition of the mortar. The vinyl ester based mortar, forms an uniform plane surface without any significant cracks or air bubbles. On the other hand, epoxy resin mortar shows a "brittle" structure. The mortar surface has considerably more cracks and pores. It cannot be determined with certainty whether these weak points are already present in the mortar before the concrete test specimens are could, for instance, be determined more precisely by means of X-ray investigations.

a) b)

Fig. 4: Example for the optical evaluation of the mortar a) Epoxy resin mortar and b) Vinyl ester based mortar

In experiments the removal of mortar worded out easily with vinyl-ester and polyester based mortar because the structure was coherent. However, in case of epoxy resin mortar and mortar based on a 2-component resin, it was considerably more difficult to remove the mortar. Due to the "brittleness" of the mortar, only small fractions flake off when the mortar is being removed. The mineral mortar also has a "brittle" texture, but good adhesion to the surface. The complete removal of this mortar from the threaded rods is therefore not always possible. The investigations suggest that the more fragile and brittle the hardened mortar is, the lower the protective effect against steel corrosion. However, this only applies to polymer-based mortars, since mineral mortars have an additional protective effect due to the high pH value and the ability to bind chlorides.

Furthermore, EDX analyses were carried out on the threaded rods to demonstrate with certainty that chlorides had penetrated to the threaded rod despite the presence of mortar. For this purpose, corrosion products were removed from the threaded rod and examined. The aim of the analysis was to detect chlorides on the threaded rods affected by steel corrosion.

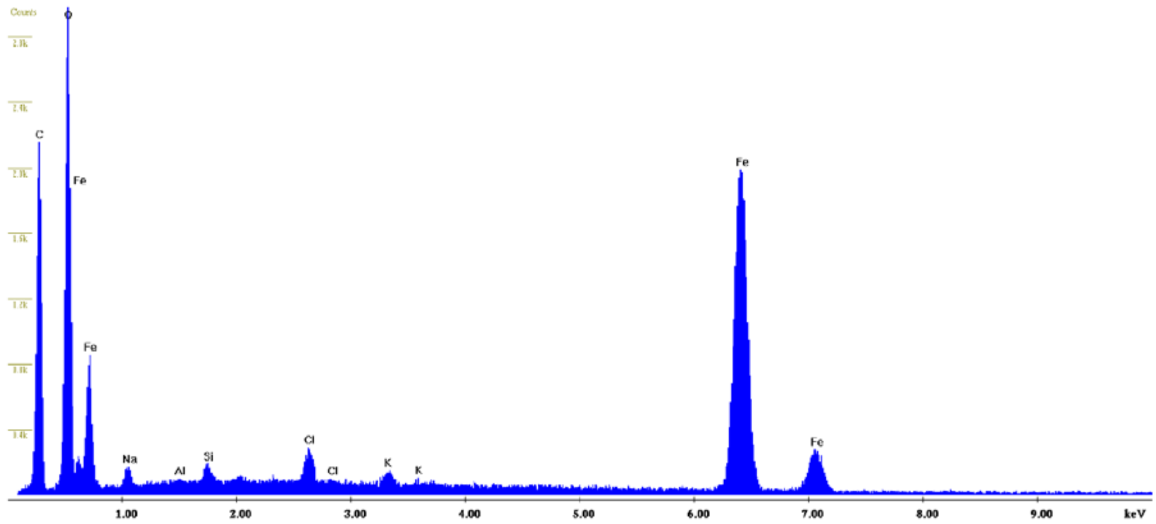

Fig. 5: EDX examination of a threaded rod which was installed with an epoxy resin based injection mortar and examined after 2 weeks of storage in artificial seawater

At a first stage, 2 reference sites were investigated, one site showed no chlorides and the other showed very high chlorides. On the basis of these reference measurements, further measurements on the threaded rods were evaluated.

Table 2: Results of the quantitative determination of the components of red rust by EDX analysis for epoxy and polyester based mortar

	Mass constancy as M.- %							
Specimen	Fe	Si	S	Na	Al	Mg	K	Cl
Reference 1	99,12	0,88	-	-	-	-	-	-
Reference 2	76,84	2,80	0,78	7,80	-	1,68	1,10	8,99
Epoxy	90,42	1,53	-	3,93	0,35	-	1,16	2,60
Polyester	58,83	22,25	-	5,26	1,02	-	11,71	0,93

As shown in Fig. 5 chlorides were detected on the threaded rods installed with an epoxy based injection mortar, just after 2 weeks of exposure. A lower chloride value was observed with injection mortars made of 2-component resin or vinyl ester. In the case of polyester based mortar, only minimal chloride values were observed (Table 2).

4. CONCLUSIONS

In the corrosion tests performed, steel corrosion was detected on the threaded rods of the bonded anchors. In the transition zone of the threaded rod, strong red rust formation was observed in almost all cases. This was expected because the threaded rods did not have any protection against corrosion.

In the end zone (surface) of the threaded rods there was no clear tendency with regard to the presence of steel corrosion with respect to exposure time and mortar type. It can be assumed that the condition of the end surface depends on the installation of the threaded rod and the mortar.

The polymer-based injection mortars showed the lowest corrosion resistance in the corrosion test. Within 2 weeks of exposure up to 10% of the red rust formation could be detected. Mineral mortar and polyester resin & vinyl ester based injection mortar showed more resistant to steel corrosion. The mineral mortar provided the best protection against corrosion as compared to other mortars tested. Even after 24 weeks, apart from a few exceptions, no signs of corrosion were detected.

Steel corrosion only occurs locally and is restricted locally. It can therefore be concluded that corrosion occurs in areas where the mortar has cracks or cavities. Since the protective effect of polymer-based injection mortars only exists because of their impermeability, a weak point in the mortar has a particularly negative impact in this case.

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