TESTS TO ASSESS THE DURABILITY OF EXPANSION ANCHORS MADE OF GALVANIZED STEEL WITH FUNCTIONAL COATING UNDER DIFFERENT STORAGE CONDITIONS

VERSUCHE ZUR BEURTEILUNG DER DAUERHAFTIGKEIT VON METALLSPREIZDÜBELN AUS GALVANISCH VERZINKTEM STAHL MIT BESCHICHTUNG UNTER VERSCHIEDENEN LAGERUNGSBEDINGUNGEN

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SUMMARY

In the building industry, planning is delayed due to long construction periods. To avoid this phenomenon, post-installed fasteners are used. Many factors must be considered to determine the load capacity and durability of fasteners. Anchors used outdoors are under the influence of environmental conditions. Therefore, their corrosion resistance is important [1].

In Germany, steel of resistance class I (galvanized) is generally used indoors. For external application, stainless steel starting from grade A2 is used. Stainless steel fasteners are significantly more expensive than those made from galvanized steel. Thus, companies are trying to manufacture galvanized fasteners with extra coating to improve their corrosive characteristics and their suitability for outdoor applications.

In this paper, a suitability method is presented where expansion anchors are subjected to three storage conditions: dry, alkaline solution of potassium hydroxide, and water storage. The test program included 115 tests. The corrosion influence on the material is evaluated. Lastly, a statement about the suitability for outdoor use is made.

ZUSAMMENFASSUNG

Im Bauwesen ist aufgrund der langen Bauzeiten die Planung oft terminlich nachläufig. Aus diesem Grund sind nachträgliche Befestigungen an Bauwerken der Regelfall. Für die Tragfähigkeit und die Dauerhaftigkeit von Befestigungen

müssen viele Faktoren beachtet werden. Befestigungsmittel, welche im Außenbereich verwendet werden, stehen unter dem Einfluss der Witterung. Insbesondere auf die Korrosionsbeständigkeit des Verankerungselements ist in diesem Zusammenhang zu achten. Stähle der Widerstandsklasse I (galvanisch verzinkt) werden in Deutschland in der Regel nur in Innenräumen verwendet. Für die Anwendung im Außenbereich wird mindestens A2 Edelstahl verwendet. Aus Edelstahl gefertigte Befestigungen sind deutlich teurer als Befestigungen aus galvanisch verzinktem Stahl. Aus diesem Grund versuchen Firmen, galvanisch verzinkte Befestigungen mit extra Beschichtungen zu fertigen, um die Korrosionseigenschaften zu verbessern. Dadurch erhofft man sich die Eignung für die Anwendung im Außenbereich.

In diesem Beitrag wird ein Eignungsverfahren vorgestellt, bei welchem Bolzenanker unter verschiedenen Bedingungen gelagert werden. Hierbei wird untersucht, wie sich galvanisch verzinkte Bolzenanker mit einer zusätzlichen Beschichtung bei unterschiedlicher Lagerung verhalten. Das Versuchsprogramm umfasst 115 Versuche. Diese wurden in einer alkalischen Lösung aus Kaliumhydroxid, Wasser und im trockenen Bohrloch gelagert. Durch die unterschiedliche Lagerung kann der Korrosionseinfluss auf das Material und die damit zusammenhängende Funktion bewertet werden. Anschließend kann eine Aussage über die Eignung im Außenbereich getroffen werden.

1. INTRODUCTION

Fasteners for outdoors use are under the influence of weather conditions. Hence, the durability of the base material and the coating must be examined. Moreover, the corrosion resistance of the fastening and its components should be investigated. In this research, torque-controlled expansion anchors made of galvanized steel are tested. The considered anchors have an approval for dry storage testing. To observe the functional capability of the anchors outdoors, the fasteners are installed in concrete and stored in three ways: dry storage, potassium hydroxide storage and water storage. This program provides information on the durability and corrosion resistance for external application anchor in combination with the storage time and the residual capacity tests.

2. TEST Procedure

2.1 Anchorage ground

The tests were carried out in non-cracked high-strength (C50/60) and in cracked low-strength (C20/25) concrete. To determine the compressive strength of the hardened concrete at the time of testing, at least 2 concrete cubes (15 x 15 x 15 cm^3) were tested according to DIN EN 12390 – 3 [5]. Table 1 lists the compressive strengths of the concrete specimens.

Table 1: Compressive strength of hardened concrete

Storage time [Days]	Compressive strength C20/25 [MPa]	Compressive strength C50/60 [MPa]
0	26.10	54.80
45	31.66	66.22
90	31.66	66.22
180	34.21	67.79
270	32.99	65.06

2.2 Program

Table 2 summarizes the test program. The size of the tested expansion anchors was M10 and the embedment depth for all tests was 58 mm. Four test series were performed: reference, AIR stored, WATER stored and KOH stored tests (see Section 2.4).

The name of the test series is composed as follows: anchorage ground (NC: non-cracked concrete/ C: cracked concrete), storage conditions (AIR/WATER/KOH) and days of storage (0 / 45/ 90 / 180 / 270). Additional reference tests were carried out in the both anchorage grounds.

Table 2: Test program

Test series	Concrete [-]	Anchorage depth h_{ef} [mm]	Test series	Concrete [-]	Anchorage depth h_{ef} [mm]
NC-Ref.	C50/60	58	C-Ref.	C20/25	58
NC-AIR-45	C50/60	58	C-AIR-90	C20/25	58
NC-AIR-90	C50/60	58	C-AIR-180	C20/25	58
NC-AIR-180	C50/60	58	C-AIR-270	C20/25	58
NC-AIR-270	C50/60	58	C-WATER-90	C20/25	58
NC-WATER -45	C50/60	58	C-WATER-180	C20/25	58
NC-WATER -90	C50/60	58	C-WATER-270	C20/25	58
NC-WATER -180	C50/60	58	C-KOH-90	C20/25	58
NC-WATER -270	C50/60	58	C-KOH -180	C20/25	58
NC-KOH-45	C50/60	58	C-KOH-270	C20/25	58
NC-KOH-90	C50/60	58	-	-	-
NC-KOH-180	C50/60	58	-	-	-
NC-KOH-270	C50/60	58	-	-	-

2.3 Installation

All bore holes are drilled with the use of a drilling rig to ensure perpendicular drill. After the hole-cleaning, the anchor was hammered down into the drilled hole to the desired depth. The length of the anchors was measured before the installation. The distance of the anchor top to concrete was measured before and after applying the installation torque. Therefore, the setting depth and the effective anchorage depth (h_{ef}) could be calculated. For the tests in cracked concrete, a hairline crack was opened prior to drilling to ensure the installation of the anchors in the crack. The crack was only used to facilitate the penetration of the liquids.

After installation of the anchor, a torque was applied to the nut with a moment of T_{inst} required by manufacturer´s printed installation instructions (MPII). According to EAD 330499-01-0601 [2], the torque moments should be reduced to 0.5 T_{inst} to account for relaxation of pre-stressing force with time after 10 minutes. However, for the tests in this program a reduction to 0 Nm applied in order to employ the storage conditions. The test in cracked concrete were installed using the same method.

The anchors were stored in dry borehole (AIR), in wet borehole (WATER) or in potassium hydroxide (KOH) (Fig. 1) for 45, 90, 180 and 270 days.

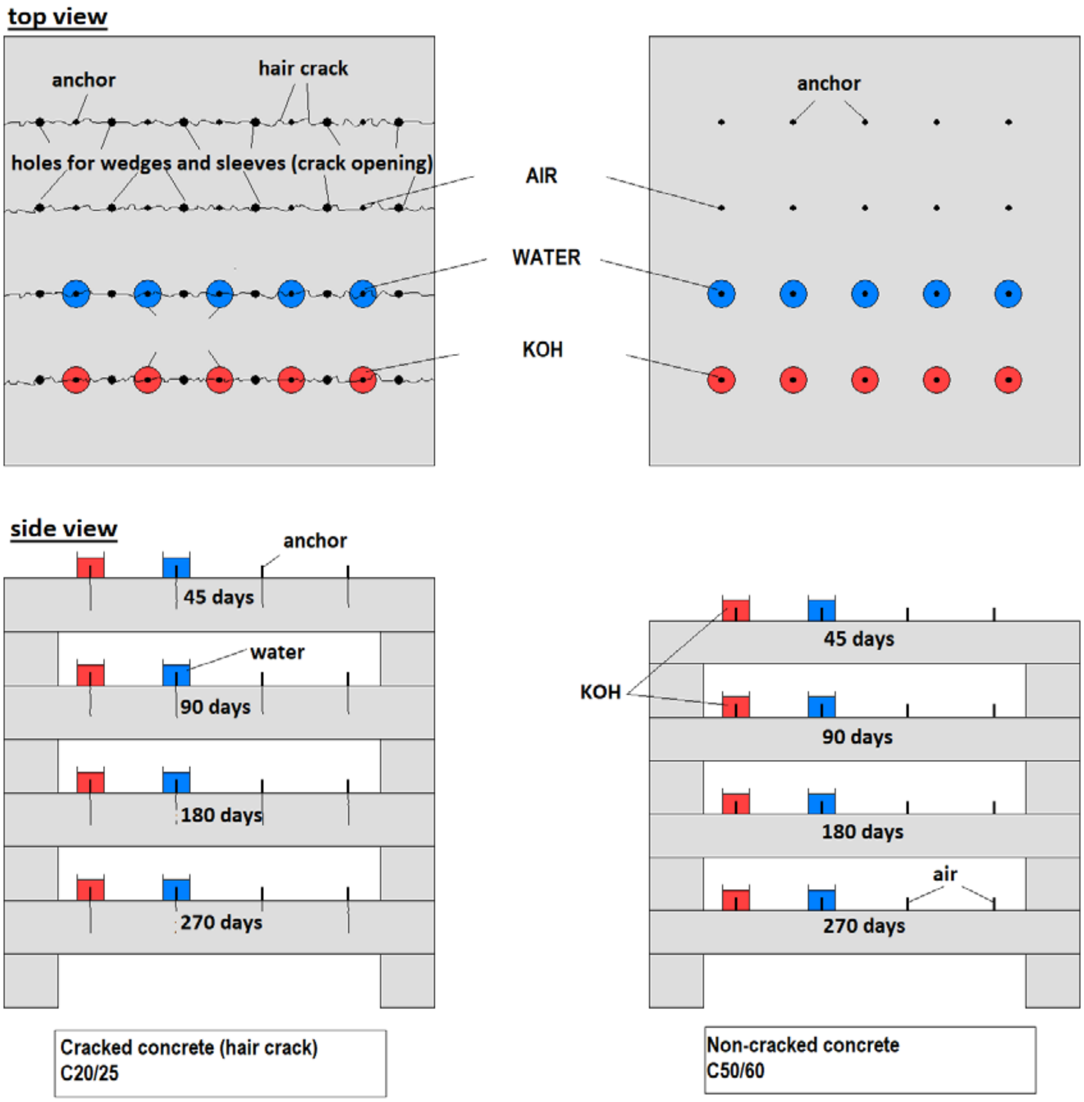

Fig. 1: Different storage conditions, after 45, 90, 180 and 270 days [AIR, WATER, KOH]

2.4 Different storage-conditions

AIR (installation and storage in dry borehole)

Storage in AIR / no additional storage conditions means storage in dry borehole. This storage method served as a reference method.

WATER (stored in water with pH value between 6.5 and 7.5)

Storage in WATER means underwater storage. To test the suitability in case of wet conditions, the anchor was stored under water. After installation, a cup with a hole is glued to the concrete surface over the anchor. The liquid entered the drilled hole without leaking out of the cup. The water level was checked every two days, so that the anchor was constantly under water. If necessary, water was filled up.

KOH (stored in potassium hydroxide with pH value > 13.2)

Storage in KOH means storing in an alkaline solution of potassium hydroxide. The anchors were stored under potassium hydroxide solution. A cup was glued over the anchor, as described in previous section. The solution was mixed with potassium hydroxide in form of flakes and distilled water. The pH value was checked with pH-indicator strips. This should be at least >13.2 [2]. If necessary, potassium hydroxide solution was filled up or potassium hydroxide in flakes form was mixed into the passed solution.

2.5 Test setup of the measuring system

All tests were performed as static confined tension tests. This description applies to the tests in both cracked and non-cracked concrete.

The test setup is shown in Fig. 2. For the tests an enough large and stiff steel plate with a hole in the middle (support plate) was used to eliminate concrete cone failure by transferring the reaction force close to the anchor into concrete. The diameter of the hole in the steel plate corresponded a value between 0.2-0.5 h_{ef} (h_{ef} = Effective anchorage depth), which can be reached by using a triangle steel plate with mouth-hole in combination with an appropriate adapting unit with a clearance hole ϕ = 0.2-0.5 h_{ef}.

The load ranges of the hydraulic cylinder and the calibrated load cell were chosen according to the expected load. The applied load and the anchor displacement were measured continually and recorded with a computer using the commercial data acquisition software CATMAN. The peak loads were reached within 1 to 3 minutes.

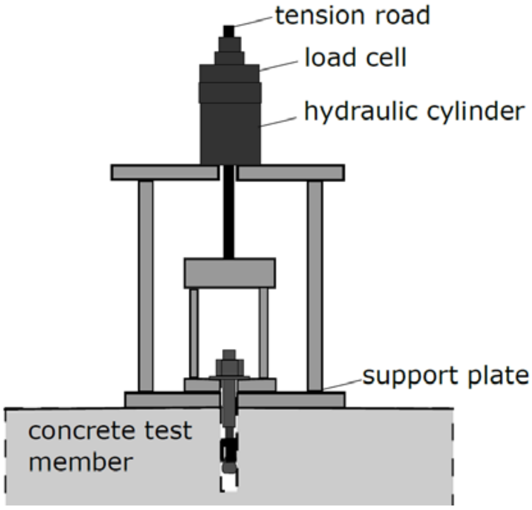

Fig. 2: Schematic drawing of the test setup used for confined tension test according to EAD 330499-01-0601 [2]

3. RESULTS AND DISCUSSION

3.1 Failure modes

The expansion anchors exhibited steel failure (S) and pull-out failure. Pull-out failure was divided in pull out with the expansion element (P) and pull through of the expansion element (P_T), see Fig. 3 [4]. Concrete cone failure was prevented by the confined test setup [3]. The steel failure occurred behind the cone of the anchor, as shown in Fig. 3. At this point, the anchor had the smallest diameter. With this type of failure, a maximum expansion of the expansion element is achieved.

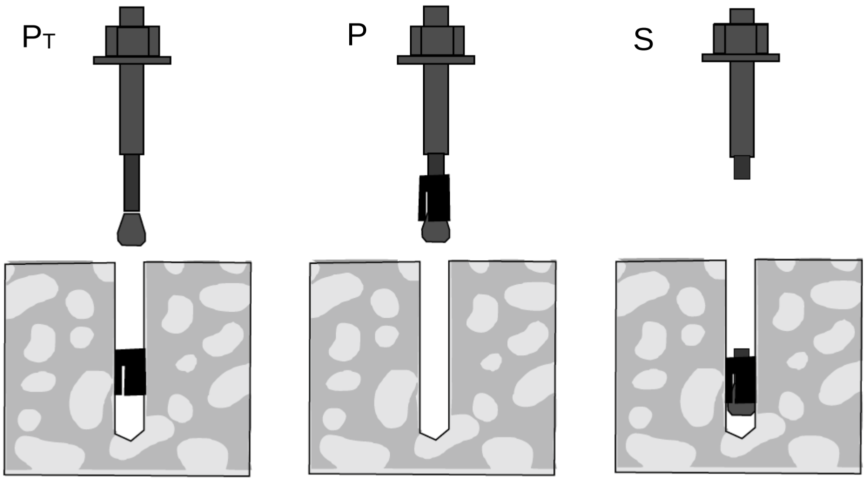

Fig. 3: Possible modes of failure

3.2 Uncracked, high - strength concrete C50/60

The tests in dry borehole show no weakening of the load capacity over time. The reference tests without storage and the anchors with dry storage (AIR) after 45, 90, 180 and 270 days failed at a load of approx. 35 kN, see Table 3 and Fig. 5.

The anchors stored in water, showed rust spots in the thread after 90 days. No influence was observed when testing the residual load capacity. All anchors failed at approx.35 kN (steel failure). Comparing the load displacement curves, no difference was observed between dry and under water storage (Fig. 4).

The anchors stored in potassium hydroxide showed partial loss in bearing capacity. After 90 days, one anchor had pull-out (P) failure. After 180 days, two anchors and after 270 days, three anchors failed in pull-out (P). The failure load of these anchors was in a range of 20-24 kN. This was a result of the increase in friction between cone and the expansion element. The KOH solution attacks the surface. As a result, the cone is not properly pulled into the expansion element.

The external friction between the borehole wall and the expansion element is smaller than the internal friction between the cone and the expansion element. The anchor is pulled out of the borehole without fully expanding.

Table 3: Test results in non-cracked, high compressive strength (C50/60) concrete

Test series	**Concrete [-]**	**Number of tests**	**Ultimate load [kN] / Failure mode**					**Mean value [kN]**	**Coeff. of variation [%]**
NC-Ref.	C50/60	5	35.01/ S	35.31/ S	36.14/ S	36.34/ S	35.30/ S	35.62	1.6
NC-AIR-45	C50/60	5	34.75/ S	34.32/ S	35.34/ S	34.27/ S	36.14/ S	34.97	2.3
NC-AIR-90	C50/60	5	35.70/ S	34.74/ S	36.09/ S	35.62/ S	35.92/ S	35.61	1.5
NC-AIR-180	C50/60	5	34.14/ S	35.85/ S	35.78/ S	34.16/ S	35.51/ S	35.09	2.5
NC-AIR-270	C50/60	5	34.96/ S	34.02/ S	34.79/ S	36.05/ S	34.15/ S	34.79	2.3
NC-WATER -45	C50/60	5	34.94/ S	34.88/ S	34.90/ S	33.68/ S	34.92/ S	34.66	1.6
NC-WATER -90	C50/60	5	36.11/ S	35.20/ S	35.38/ S	34.96/ S	31.07/ P	34.55	5.5
NC-WATER -180	C50/60	5	34.28/ S	34.94/ S	36.09/ S	35.94/ S	35.28/ S	35.31	2.1
NC-WATER -270	C50/60	5	34.94/ S	34.29/ S	34.77/ S	34.79/ S	35.16/ S	34.79	0.9
NC-KOH-45	C50/60	5	34.78/ S	34.97/ S	35.00/ S	35.29/ S	34.73/ S	34.95	0.6
NC-KOH-90	C50/60	5	35.67/ S	36.11/ S	34.96/ S	34.30/ S	23.88/ P	32.98	1.6
NC-KOH-180	C50/60	5	34.77/ S	23.32/ P	35.38/ S	34.77/ S	21.59/ P	29.96	2.0
NC-KOH-270	C50/60	5	20.99/ P	35.84/ S	22.70/ P	35.07/ S	23.79/ P	27.68	25.9
P: Pull out; P_T: Pull through expansion element; S: Steel failure									

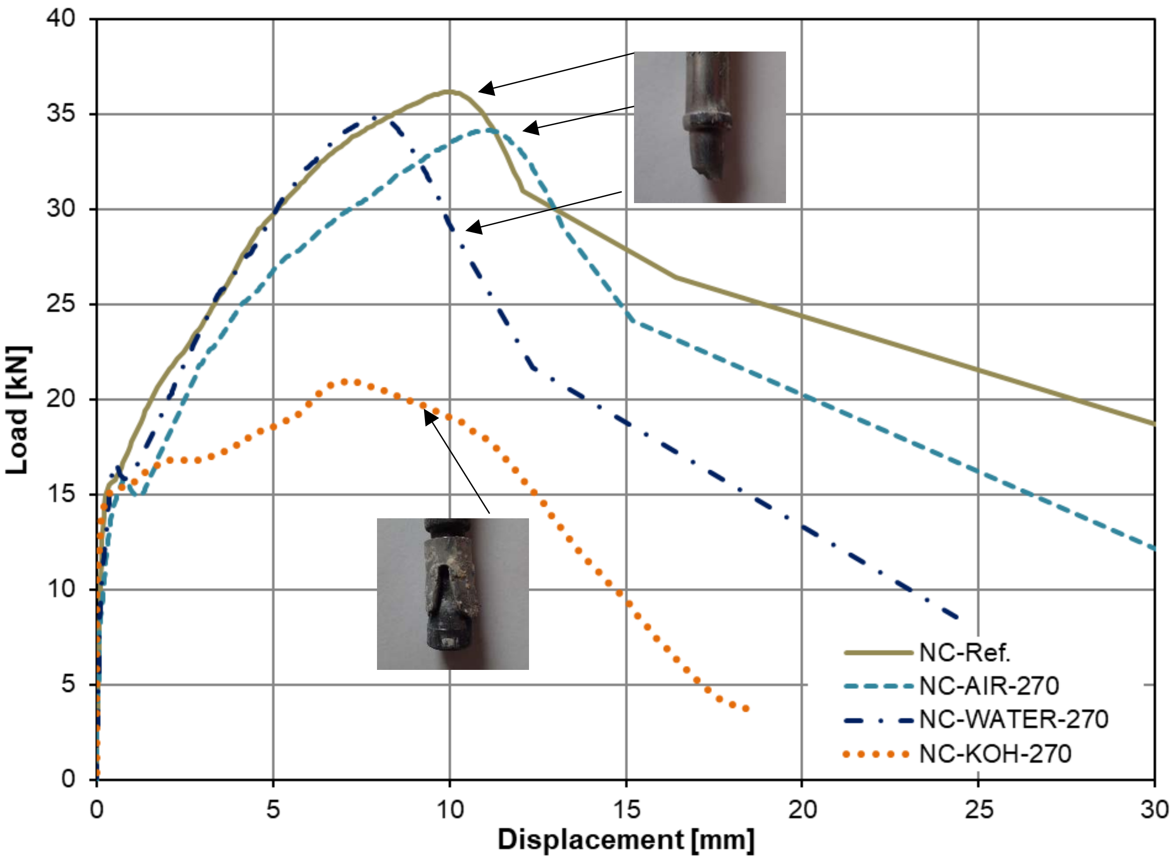

Fig. 4: Load-displacement curves of throughbolt in non-cracked, high compressive strength (C50/60) concrete

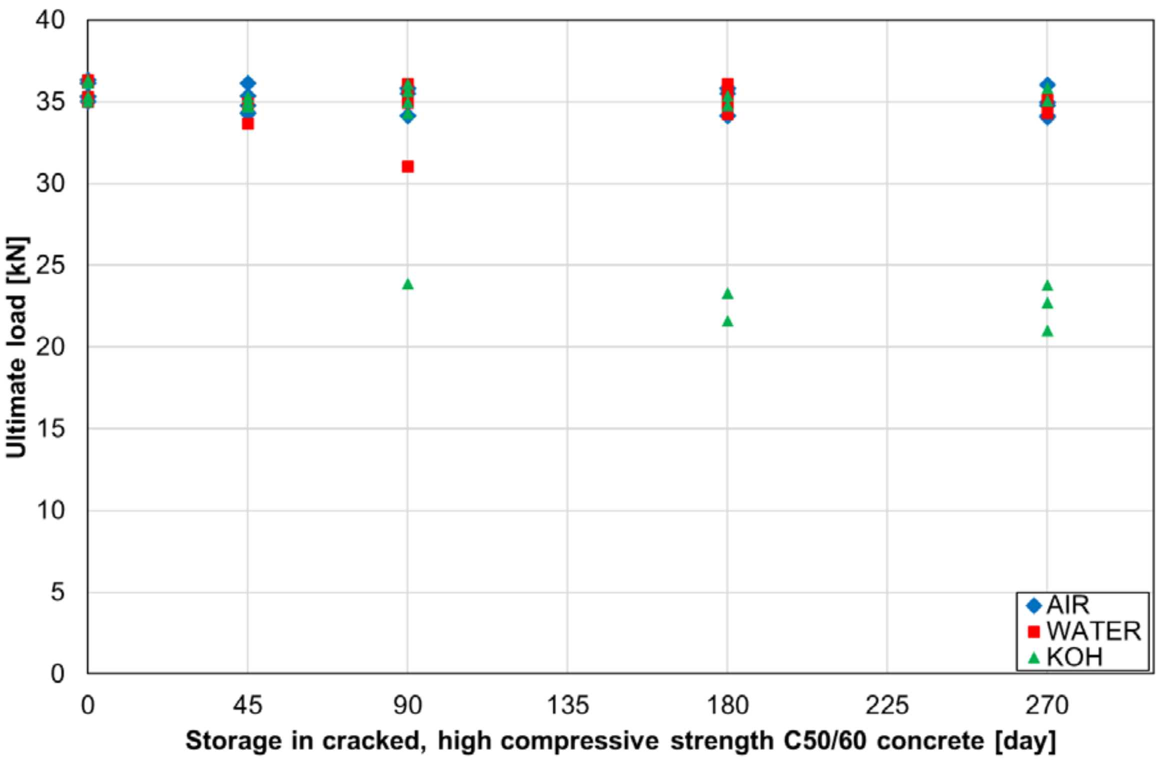

Fig. 5: Ultimate load N_U in non-cracked, high compressive strength (C50/60) concrete

3.3 Cracked, low - strength concrete C20/25

The results in cracked low - strength concrete showed greater variation in each condition. The reference tests as well as the tests stored in the dry borehole showed similar failure loads. After 270 days of storage, a mean failure load of 32.5 kN was reached in tests with dry borehole. The most common failure mode was pull through of the expansion element, see Table 4.

Table 4: Test results in cracked, low compressive strength (C20/25) concrete

Test series	Concrete [-]	Number of tests	Ultimate load [kN] / Failure mode					Mean value [kN]	Coeff. of variation [%]
C-Ref.	C20/25	5	29.46/ P	33.01/ P	30.53/ P_T	31.93/ P_T	30.45/ P_T	31.08	4.5
C-AIR-90	C20/25	5	30.98/ P_T	30.40/ P_T	27.76/ P_T	34.22/ P_T	30.54/ P_T	30.78	7.5
C-AIR-180	C20/25	5	33.96/ P	34.59/ P	32.02/ P	30.48/ P	32.63/ P	32.73	5.0
C-AIR-270	C20/25	5	34.44/ P	29.13/ P_T	34.45/ P_T	30.72/ P_T	33.67/ P_T	32.48	7.5
C-WATER-90	C20/25	5	31.81/ P	34.66/ P	35.91/ S	34.67/ P_T	27.61/ P	32.93	1.1
C-WATER-180	C20/25	5	31.12/ P	29.42/ P	27.79/ P	34.26/ P	32.67/ P	31.05	8.2
C-WATER-270	C20/25	5	31.04/ P	32.43/ P	33.80/ P	32.06/ P	31.60/ P	32.18	3.2
C-KOH-90	C20/25	5	21.77/ P	34.63/ S	17.47/ P	14.02/ P	25.39/ P	22.65	35.1
C-KOH -180	C20/25	5	10.61/ P	6.80/ P	14.39/ P	18.52/ P	14.29/ P	12.92	34.2
C-KOH-270	C20/25	5	13.79/ P	20.47/ P	24.27/ P	17.31/ P	10.66/ P	17.30	31.0
P: Pull-out; PT: Pull through expansion element; S: Steel failure									

This failure was due to the lower strength of the concrete. The anchors by fully expanding form very high forces against the borehole wall. By pressing in the borehole wall, the cone can pull itself much deeper into the expansion element until it pulls through. The external friction between the borehole wall and the expansion element is greater than the friction between the cone and the expansion element [4].

The anchors that failed in pull - out (P) showed damage of the expansion element. This is because the expansion element was damaged by full expansion in the borehole. These anchors had similar load displacement behavior as the anchors which had the pull through (P_T) failure.

The tests under water storage showed no changes in the ultimate load compared to the dry stored tests. The water stored anchors exhibited larger displacements than those dry stored (reference tests and AIR stored). The internal friction between the cone and the expanding element increased over time. The cone needs significantly more force to be pulled into the expansion element. This could explain the larger displacements at the failure load illustrated in Fig. 7. The C-WATER-270 curve was characterized by a large load plateau. The maximum load was reached after a second expansion and consequently with more displacement. Only the water and air stored tests are compared in Fig. 6, as these tests failed with similar load level (Fig. 8).

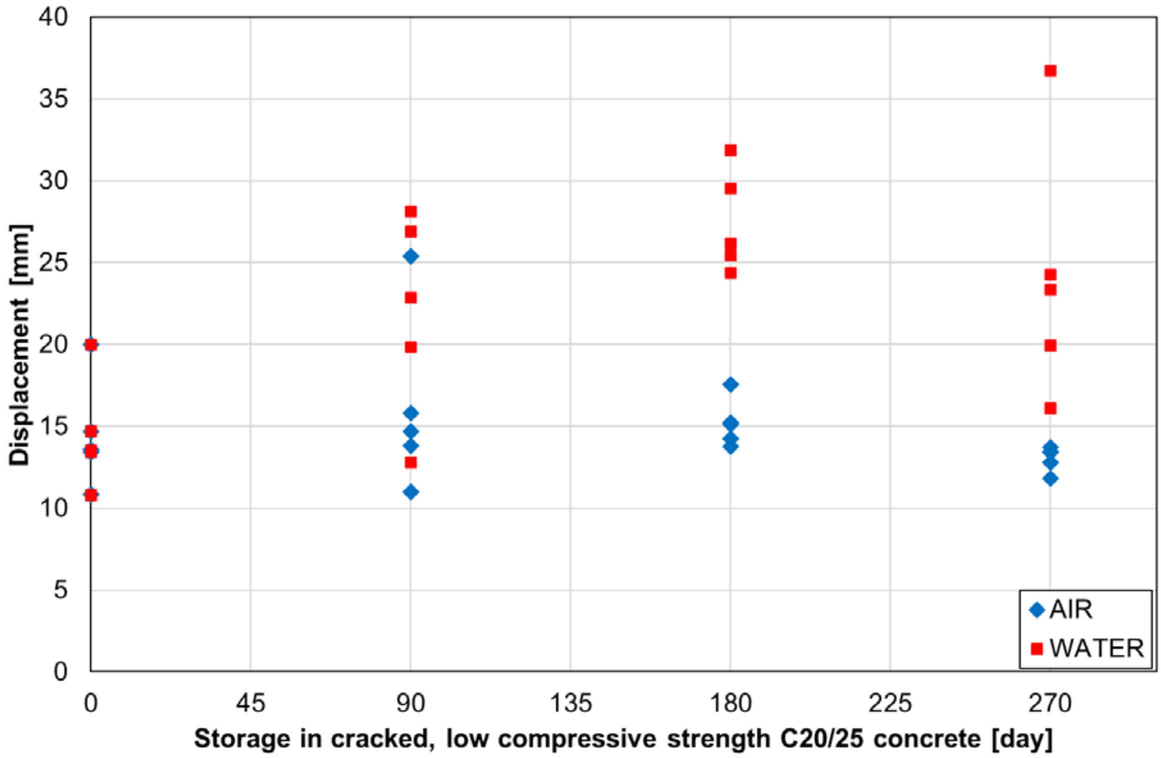

Fig. 6: Displacement over time with WATER and AIR storing in cracked, low compressive strength (C20/25) concrete

The tests stored in KOH showed significantly lower failure loads compared to the dry and water stored tests. The failure load after 90 days was lower due to a large loss of the expansion ability of the anchors, see Table 4. Similar behavior was observed after 180 days. The anchors lost the full expansion ability; therefore, the load did not increase over time. The internal friction between expansion element and cone was so great that the anchor could not expand any more. This resulted in a loss of external friction between the borehole wall and the expansion element. A typical load-displacement behavior can be seen in Fig. 7.

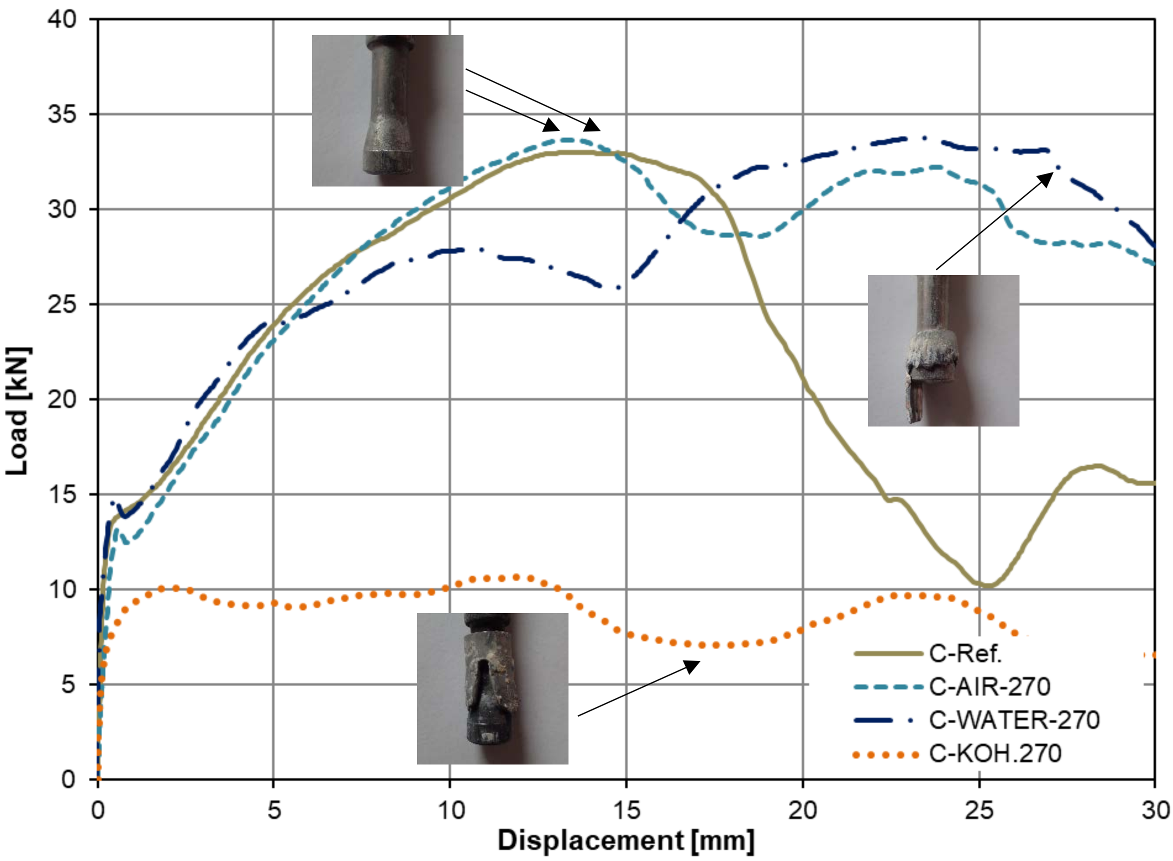

Fig. 7: Load-displacement curves of throughbolt in cracked, low compressive strength (C20/25) concrete

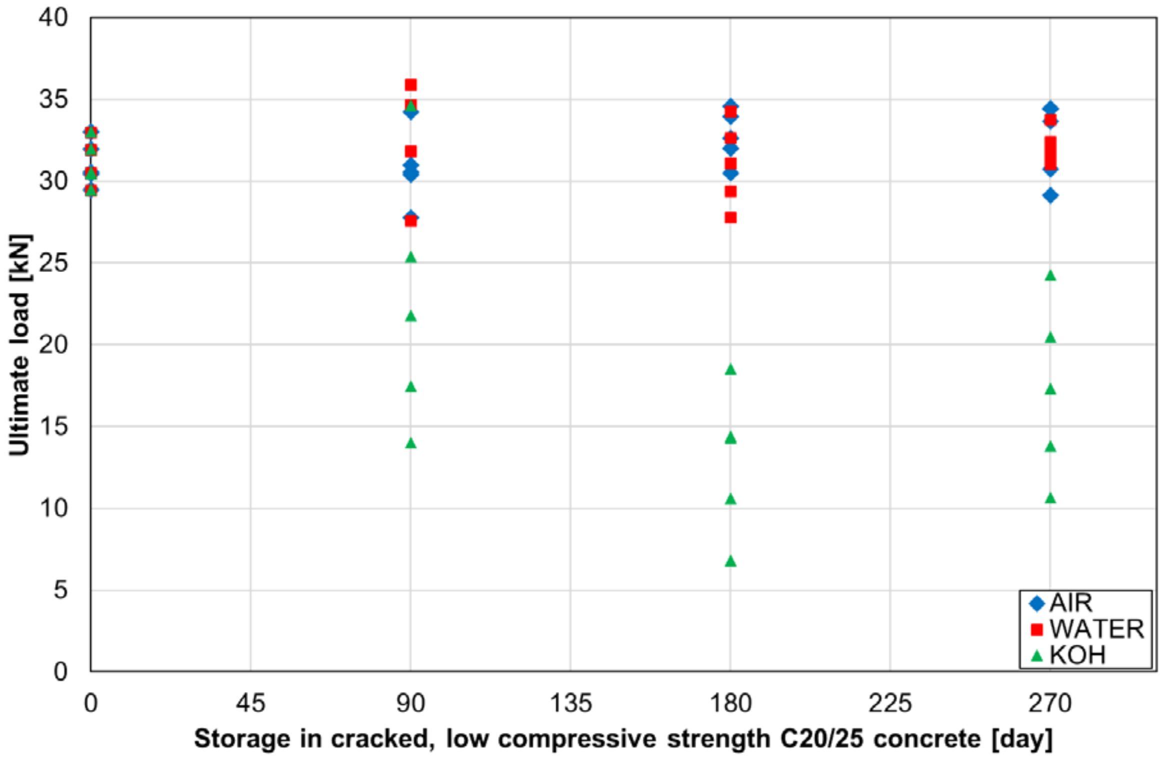

Fig. 8: Ultimate load N_U in cracked, low compressive strength (C20/25) concrete

3.4 Conclusion

The external application of torque-controlled expansion anchors made of galvanized steel must be critically evaluated. This research showed a possible method for suitability testing. The decrease of the expansion capacity in the potassium hydroxide solution as well as in water indicates that the galvanized steel anchors with extra coating are not suitable for external applications.

The test program was carried out in cracked and non-cracked concrete. The results in the cracked concrete were more significant. During storage, after 45 days, a leaking of the liquids through the crack in the concrete could be observed. This indicated that the KOH solution and water reached the anchorage depth.

In non-cracked concrete, moisture could not be guaranteed to flow through. This became noticeable from the different failure modes in the KOH solution (Table ***3***).

The anchors installed in non-cracked concrete under dry and water storage showed no changes in ultimate load but just in the load-displacement behavior. The tests in KOH solution, exhibit mostly no influence of the storage. Only 30% of these anchors showed an effect from the potassium hydroxide solution.

In the cracked concrete tests, considerable influences on the load capacity can be seen depending on the storage condition. With increasing storage time, the negative effect of the solutions on the load carrying capacity of the anchors increased. It is recommended that expansion anchors are installed in the hairline crack to avoid an incorrect assessment for fasteners with external applications.

Further research and new test methods should be developed for anchors made of galvanized steel with an extra coating. Comparison tests in concrete slabs of the same compressive strength (non and cracked concrete) should be carried out to establish whether the hair cracks facilitate the propagation of the solutions inside the concrete thus influencing the carrying capacity and the behavior of the expansion anchors.

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