Basic Study on Rust Prevention in Maintenance of Rebars for Concrete Structures

Cracking and rainwater penetration easily occur at construction joints of reinforced concrete (RC) structures, so there is concern over early corrosion of rebars there. On the assumption that prevention of corrosion of rebars at such joints could alleviate the issue of long-term durability that greatly affects maintenance of RC structures, we carried out accelerated corrosion tests of rebar. In that, we used rebar samples that had rebars and different types of existing antirust agent and concrete samples that had embedded rebars to simulate construction joints. In the tests, we checked the condition of corrosion and compared to Corrosion Grades (Degree of Corrosion) indicated in existing guidelines, to evaluate the corrosion level.

1 Introduction

Reinforced concrete (RC) structures must maintain sufficient proof strength and durability and achieve required performance throughout their service life. When constructing an RC structure in limited construction space, it is often constructed in sections (constructed in separate periods of time). Such a structure has construction joints (Fig. 1), and cracks may occur at or near those joints and cause water penetration. In this way, air and water easily penetrate construction joints with cracks and create an environment where rebar easily becomes corroded, likely causing adverse effects on proof strength and durability of the RC structure. That greatly affects maintenance of the RC structure too.

Thus, on the assumption that prevention of corrosion of rebars at such joints could alleviate the issue of long-term durability that greatly affects maintenance of RC structures, we carried out accelerated corrosion tests of rebars using rebars samples that had rebars and different types of existing antirust agent. We also carried out the same tests using concrete samples that had embedded rebars and rebars with different types of existing antirust agent to simulate construction joints. This article will cover those tests and test results.

2 Testing Method

As the method of accelerated corrosion testing of ordinary steel, we used a salt water spray test method, where +/-0.5% salt water is used in a test cycle of two hours of salt water spraying, four hours of drying and two hours of leaving in wet condition, based on JIS Z 2371. But, in the study, we carried out an accelerated corrosion test for a test cycle of repeated immersion in salt water and drying with the aim of causing steel more corrosion.

<Test conditions for one cycle>
Immersion in salt water (around 6.7%, 60 °C): 4 hours
Drying at 60 °C: 4 hours
8 hours

3 Details of the Samples

We made a basic sample using a piece of rebar generally used for RC structures and other samples using pieces of rebars each applied with a different antirust agent. Then we put them in a test cabinet for accelerated corrosion tests. The mass and rebar diameter of those samples were measured before the tests and after 10, 50, 100, 200 and 525 cycles.

3.1 Rebar Samples
Table 1 and Fig. 2 show the details of the samples. We used samples of 1) rebar, 2) rebar completely coated with antirust agent, and 3) rebar half-coated with antirust agent. The purpose of 1) is to check rust development on rebar alone, of 2) is to check the difference of rust development due to application with antirust agent, and of 3) is to check the difference in rust development on the border of the coated part and uncoated part. For the test, we selected four commercial antirust agent products. On the cut surface of rebars, we applied epoxy resin.

3.2 Concrete Samples
The concrete samples simulated construction joints of reinforced concrete. Table 1 and Fig. 3 show the details of the samples.
The gap between two concrete blocks shown in Fig. 3 is a model of a concrete crack wider than usual ones. We made the gap by placing a 3.2 mm-thick steel plate between the blocks and removing it after concrete solidification to create an environment where salt water and air (when dry) repeatedly entering from the gap made rebar in the concrete more easily corroded. The samples are of two types: 1) usual concrete with embedded rebars coated with antitrust agent and 2) concrete mixed with rust-inhibiting admixture and embedded with rebars.

### 4 Test Results

#### 4.1 Evaluation Method of Corrosion Level

In order to compare the corrosion level of rebars in this test, we had to evaluate the corrosion level of each sample according to a uniform standard. In this context, we referred to Recommendation for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structure (text in Japanese) of the Architectural Institute of Japan\(^1\) and Tokkin Concrete-zukuri Kenchikubutsu no Taikyusei Kyo Gijutsu (in Japanese) edited by the Committee for Promoting Building Durability Improvement Technology of the Japan Institute of Construction Engineering\(^2\) in compiling the corrosion test results of each sample. Based on the photos and descriptions in those reference books, we visually judged the corrosion level of rebars of each sample. Tables 2 and 3 list the descriptions of the above-mentioned reference books on the corrosion level (Corrosion Grade\(^3\), Degree of Corrosion\(^4\)).

#### 4.2 Rebar Samples

**4.2.1 Uncoated Rebar (T Samples)**

(1) Corrosion of the Samples (Fig. 4)

Fig. 4 shows corrosion of the samples after specified test cycles. After 10 cycles, thin rust occurred at the ridges and on the surface of the rebars of each sample. Compared to the evaluation indicators in Tables 2 and 3, the corrosion level at that time was Corrosion Grade III (Degree of Corrosion III). After 50 cycles, much blackish rust and some rust bulges occurred on every sample, making ridges of rebars almost unrecognizable. At that time, the corrosion level is assumed to have been over Corrosion Grade V (Degree of Corrosion IV). After 100 cycles, blackish rust increased on the surface of rebars, and rust bulges and cracked rust occurred. After 200 cycles, large cracks and lustrous black rust occurred on samples T-1 and 2.

On the surface of samples T-3 to 5, bulged, porous brown rust occurred in spots. After 525 cycles, rust on every sample greatly expanded and flaked off at the touch. On the rust, many cracks occurred in the direction of the rebar longitudinal axis.

(2) Rebar Mass Change Rate

Based on the mass measured at the specified test cycles, we calculated mass change rates of rebar samples T-1 to 5 with uncoated rebar. The calculation results are shown in Fig. 5. The rate was calculated as the ratio to the mass before the tests. The results demonstrate that every sample showed almost the same tendency of mass increase. The gradient of the lines indicates that the mass change rates were low at the initial stage, but the mass of each sample sharply increased at 50 to 100 cycles, 100 to 200 cycles and 200 to 525 cycles. Taking into account the corrosion level evaluated after each specified cycle in (1), the corrosion level (Corrosion Grade and Degree of Corrosion) is indicated on the chart too. As shown, the level after around...
10 cycles reached Corrosion Grade III (Degree of Corrosion III) and after around 50 cycles Corrosion Grade V (Degree of Corrosion IV).

4.2.2 Rebars Coated with Antirust Agent (A to D Samples)

(1) Corrosion of Samples

Fig. 6 to 8 show the corrosion of the samples after some specified test cycles. On every sample after 10 cycles, rust spots occurred around the ridges of rebars in the part coated with antirust agent, and rust occurred around the ridges of rebars in the uncoated part (Fig. 6). The corrosion level of the coated part was Corrosion Grade II (Degree of Corrosion II) compared to the indicators in Tables 2 and 3. After 50 cycles, rust extended around the ridges of rebars of A to C samples (Corrosion Grade IV, Degree of Corrosion III). Corrosion of the coated part of D samples was relatively mild (Corrosion Grade II to III, Degree of Corrosion II to III). With every sample, the rust border between the coated part and the uncoated part was clearly recognizable. Rust on the uncoated part was similar to the rust of the T samples (Fig. 7, coated parts shown in squares). After 525 cycles, rust expanded and longitudinal cracks occurred on every sample. All samples were of almost the same corrosion state, so we found no clear difference in appearance from the uncoated rebar T samples. With the D samples, the coating was observed together with rust (Fig. 8).

4.2.3 Rebars after Rest Removal

We tapped off with an iron paddle the rust from each rebar sample that went through the accelerated corrosion tests under the same conditions, and then we gently scraped the rust off from the samples with a wire brush.

(1) Rate of Remaining Rebar Mass

We figured out the rate of the remaining mass of the rebar samples from which rest was removed. Based on the average mass of samples T-1 and T-2 in the same lot before the test as the base rebar mass before corrosion, we calculated the ratio of the mass of the rebar after removing rust to that base rebar mass as the rate of the remaining rebar mass.

The calculation results are shown in Fig. 9. With the samples coated with antirust agent, the rate of the remaining rebar mass was higher by 5 - 10% than that of the uncoated samples. With the C and D samples, we found that coating the entire sample did not necessarily have higher antirust effect than half-coating.

(2) Rate of Remaining Rebar Diameter

We also calculated the rate of the remaining rebar diameter. Based on the nominal diameter of D19 deformed steel bar (19.1 mm) used for the rebar samples as the base rebar diameter before the test, we figured out the rate of the remaining rebar diameter of the rebars from which rest was removed. The calculation results are shown in Fig. 9 and photos of the cut surfaces of the rebars in Fig. 10. As the rebar diameter measurement values, we took the average values of two orthogonal diameters measured on the cut surfaces of the rebars from which rest was removed.

Fig. 9 shows a similar tendency in the rates of remaining mass and diameter of the rebars, while some differences can be seen in part. Fig. 10 shows that the cross-sections of the rebars were not evenly corroded. The rebar surfaces were partly flipped up because the rebars were severed with a cutter.
4.3 Concrete Samples

4.3.1 Reinforcement in Concrete Samples

We measured the mass of the concrete samples and visually checked their appearance change from before the test and through the specified 525 test cycles.

(1) 0 to 200 Cycles

We found no remarkable appearance change up to 200 cycles. Some rust powder was adhered, however no cracks occurred on concrete.

(2) After 525 Cycles

On every concrete sample mixed with rust-inhibiting admixture, cracks of different width and length occurred (Fig. 11). Next, to check the state of corrosion of the rebars in the concrete samples, we broke up the concrete and took out the rebars (Fig. 12). The rebars of some samples did not seem to be completely exposed because the paste penetrated the gaps at casting of concrete. We found no significant difference in reinforcement corrosion between at the center of the gap and inside the concrete.

(3) Evaluation of Corrosion Level

As done on the rebar samples, we evaluated the corrosion level of the rebars embedded in concrete based on the descriptions in Tables 2 and 3 and the photos in the reference books. Comparing with the description in Table 2, we concluded that sample f was Corrosion Grade III to IV; comparing with the photos, we concluded that samples a, f and g were Corrosion Grade II. Other samples were judged to be Corrosion Grade IV from the description and Corrosion Grade III upon the photos. The tests and evaluations demonstrated that sample f applied with the epoxy antirust agent showed higher antirust effect than others.

5 Conclusion

We carried out the aforementioned basic experiments on rust prevention of rebar that affects maintenance of RC structures. The results revealed different antirust effects of different antirust agents and rust-inhibiting admixtures. Establishing rust prevention performance that lasts the service life of structures will contribute to improvement of structure durability and reduction of maintenance work.

Reference:

1) “Recommendations for Practice of Survey, Diagnosis and Repair for Deterioration of Reinforced Concrete Structures [text in Japanese]” (Architectural Institute of Japan, December 2000)


3) JIS G 3112: 2010 Steel bars for concrete reinforcement (Japanese Standards Association, February 2010)