Research Article

Corrosion Characteristics of Anchor Cables in Electrolytic Corrosion Test and the Applicability of the Test Method in Study of Anchor Cable Corrosion

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The selection of corrosion test method in the corrosion study of the prestressed anchors is an important issue. In this paper, the corrosion test of anchors was conducted with electrolytic corrosion test method. The corrosion characteristics of the anchor cables were examined. The effects of sodium chloride solution concentration, current, test time, and prestress level on corrosion were studied. The applicability of electrolytic corrosion method in anchor cable corrosion study is discussed subsequently. The results show that the corrosion of the anchor appears to be uniform corrosion. With the corrosion of the anchor, the central wire of the cable was basically not corroded, and the cross-sectional shape of the outer wire changes from a round to fan shape. The sodium chloride concentration and prestress level have no obvious effects on the corrosion of the anchor. The variation of test time does not affect the difference between the measured and theoretical calculated results, while a proper current in the electrolysis test may help reduce the difference. The measured corrosion rate fluctuates from −4% to 10% and tends to be higher compared with calculated results based on Faraday's law. The study indicates that the electrolytic corrosion test is applicable in the anchor corrosion study.

1. Introduction

With the abundant applications of rock anchors in water conservancy, bridge, and mining projects, the deterioration of the anchor cables caused by corrosion has become an issue of concern [1–5]. The corrosion of anchor cables may induce serious problems such as the loss of anchor's locked force which may diminish the anchor's function. The corrosion of anchors can also incur the fracture of the grout and the damage of the anchor system, which may lead to the destruction and even failure of the structure. Therefore, studying the corrosion characteristics and development laws of anchor cables has great significance.

Corrosion tests of metals are effective ways for investigating the corrosion of steels in engineering structures, while the selection of an appropriate corrosion test for the anchors with different study purposes is an issue worth studying. Anchor cable corrosion tests include field tests and laboratory tests. The field tests can be divided into two categories. One is to excavate and acquire anchor cables that have serviced for a certain number of years [1, 2], and the other is to conduct on-site corrosion tests in the field with the artificial environment created to simulate the actual working conditions of anchor cables [3]. Although field tests can obtain the most directly actual conditions of the anchor cable corrosion, such problems as high cost and long time

consumption are issues that must be considered. Laboratory corrosion tests, including artificial climate method, immersion corrosion method, and salt spray method, were widely performed by researchers in corrosion studies [4–8]. The corrosion morphology of the samples obtained by both the artificial climate method and the immersion corrosion method is consistent with that of the actual cable samples in service [9, 10], so it is feasible to use these methods to explore the corrosion mechanism of the cables. However, the problem with these laboratory corrosion tests is that the corrosion rate of the cable samples obtained is relatively low. For example, most of the corroded samples obtained by Liu [4] in the laboratory accelerated corrosion test based on the artificial climate method had a corrosion rate of less than 1.0% after four months' test. This is relatively inefficient for studying the effects of the corrosion on the mechanical properties of the anchor cable. As a common method that can efficiently obtain high corrosion rate samples, the electrolytic corrosion test is widely used in the corrosion study of steel bars [10–17]. Though these researches indicated that application of electrolytic corrosion test on steel bars is common in concrete, the systematic study of the applicability of electrolytic corrosion method has not been reported. During the previous researches, the determination of the sodium chloride solution concentration and current in the electrolytic corrosion test basically depends on experience instead of theoretical or test data reference. Also, the application of electrolytic corrosion method in anchor cable corrosion study is infrequent and its applicability needed to be verified.

In this study, the electrolytic corrosion test of anchor cables was conducted. The corrosion laws of anchor cables with different sodium chloride solution concentrations and stress levels were explored, and the corrosion morphology and its characteristics of anchor cable were analyzed. The applicability of electrolytic corrosion test in the anchor cable corrosion study was discussed.

2. Experiment Program

2.1. Test Devices.
The designed electrolytic corrosion test device of unstressed cable is shown in Figure 1. The electrolyte container was a plastic box made of polypropylene. The cathode was made of a copper bar with a diameter of 3.5 cm to meet the requirement that the surface area should be larger than that of anode sample. One end of the copper bar was connected with the negative electrode of the power supply with wire. The cable sample and the copper bar were fixed in the corrosion box at the same height on the glass support plate below. A DC power supply was selected to provide the current. The cable sample and the copper bar were connected to the positive electrode and the negative electrode of the power supply correspondingly. Then the sodium chloride solution was poured into the box to the height 5 cm above the copper bar. Finally, the power supply was turned on at the preset current to start the test.

For the test of prestressed anchor cable, the cable has to be tensioned firstly on a steel support frame. The steel support frame consisted of 2 steel plates and 4 steel supporting tubes, as shown in Figure 2(a). The steel plates were square with a length of 400 mm for each edge and a thickness of 25 mm. A hole of 20 mm in diameter was set in the center of the plate to allow the cable to pass through. The four steel tubes were seamless with an outside diameter of 40 mm and a wall thickness of 3.5 mm. The bearing capacity of the support frame was designed to ensure that the compressive strength met the requirements of maximum tensile force in the tests. Two holes were opened at both ends of the solution vessel to allow the anchor cable sample pass through. Two PVC connectors were mounted in the vessel holes for easy sealing. One end of the steel strand was fixed with a nut. A strain gauge transducer was installed between the nut and steel support frame to monitor the tension load, as shown in Figure 2(b). A tension jack was used at the other end to tension the strand. After the tension was completed, an asphalt sealant was used to seal the gap between the strand and the solution vessel (Figure 2(c)). It should be noted that the asphalt sealant also should be used to seal the gaps between the cable wires at the corresponding position during the sample preparation to prevent the solution leaking. After sealing, the length of the sample immersed in the solution was also about 34 to 35 cm. The other steps were similar to the unstressed sample test. Finally, the power supply was switched on and the test was started, as shown in Figure 2(d).

After the test is completed, the corroded cable samples were moved out from the container and cut for sampling. The corrosion products on the samples were then removed with rust remover solution and manual wiping. The sample was then weighed and measured to calculate the corrosion rate based on the mass loss percentage.

2.2. Samples.
The 1x7-15.2-1860 steel strands in ASTM A416/A416M-17 [18] were selected as the samples, which are 5.2 mm in diameter for center wire and 5.0 mm in diameter for six outer wires. The parameters of the cable in the standard were summarized in Table 1. It should be noted that the measured weight of the cable in the laboratory was 11.097 g/cm (1109.7 kg/1000 m). The measured weight was used in the following corrosion rate calculation.

The length of the unstressed cable sample was set to 40 cm. The cable was disassembled to remove the grease and then reassembled back. A copper wire was connected to one end of the sample. In order to prevent the effect of the fresh cut on the electrolytic corrosion, two PVC caps and silica gel were used to seal both the sample ends. The length of strand sample immersed in the electrolyte approximately ranged between 34 and 35 cm after putting on the PVC caps. The length of prestressed strand sample was set to 200 cm so that the strand can be prestressed on a designed steel support frame. The sample was also degreased the same as the unstressed sample before test.

2.3. Test Influencing Factors.
According to Faraday's law, the consumption of iron in the electrolytic test was mainly controlled by current and time, so these two parameters were taken as influential factors. In the electrolytic test, the
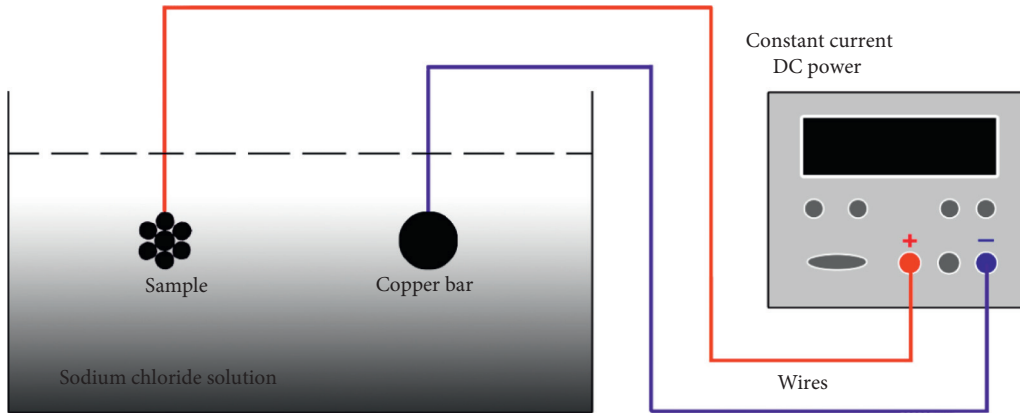
FIGURE 1: Diagram of the anchor cable electrolytic corrosion test for unstressed anchor cable.
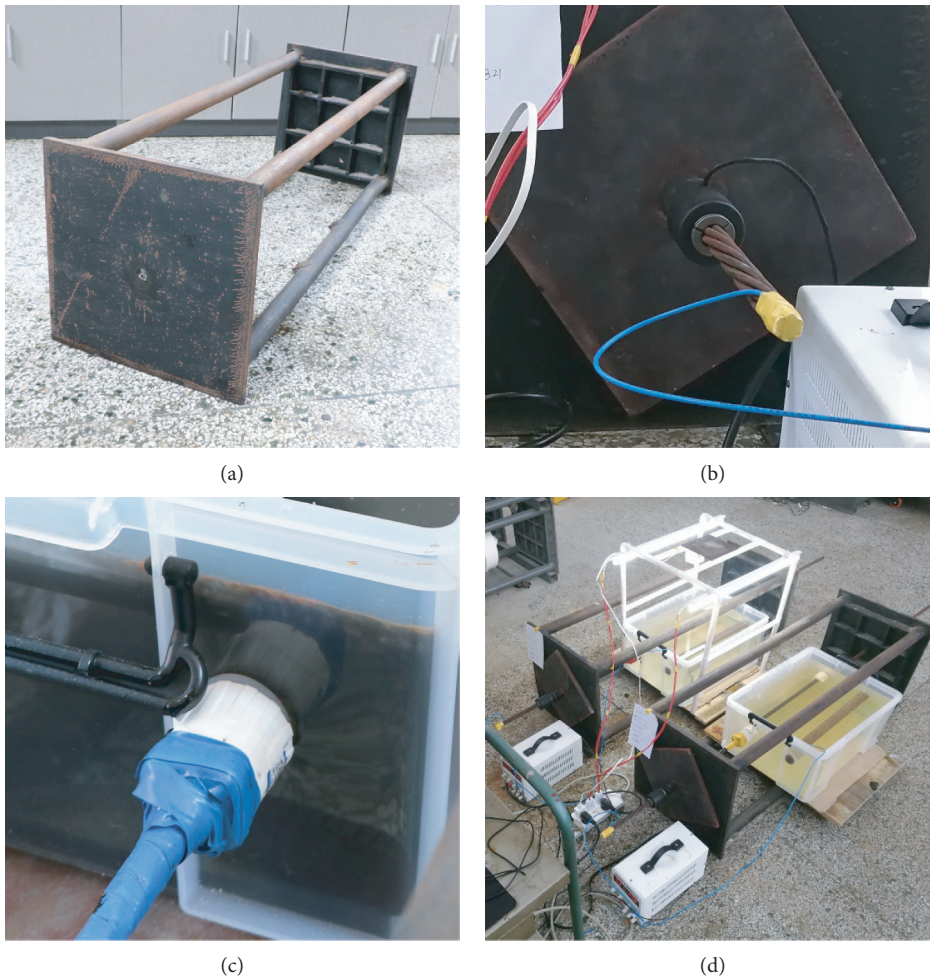

FIGURE 2: Electrolytic corrosion test of prestressed anchor cable. (a) Steel support frame; (b) strain gauge transducer; (c) sealing of the vessel; (d) appliance of the test.

TABLE 1: Parameters of anchor cable samples.

Nominal diameter (mm)	Minimum breaking strength (kN)	Steel area (mm^2)	Weight (mass), kg/ 1000 m	Permissible variations in diameter (mm)
15.2	261	140	1100	+ 0.65 −0.15

electrolyte solution was necessary to form an electrolytic cell. Based on the experiences in similar studies [10–17], the sodium chloride solution was selected as the electrolyte solution. The mass percentage of sodium chloride was taken as a factor. The anchor cables in service were usually pre-stressed, and the influence of stress on corrosion was a factor that should be considered. In summary, four factors with four levels for each were considered in the test. A total of 35 tests were conducted, as shown in Table 2.

3. Results

3.1. Corrosion Rate of Anchor Cable Samples.

3.1. Corrosion Rate of Anchor Cable Samples. The corrosion rate is normally used to evaluate the degree of the corrosion. To evaluate the corrosion rate of the samples, the calculated theoretical corrosion rate based on Faraday's law was introduced for comparison. During the electrolytic corrosion test of anchor cable, one Fe atom lost two electrons to form Fe^{2+}. Based on Faraday's law [14–16], the consumption of Fe in the reaction can be calculated as

$$m = \frac{Itn}{2F},$$ (1)

where I is the current (A), t is the time (s), F is the Faraday constant which equals 96487 C/mol, and n is the molar mass of Fe which is about 55.845 g/mol. Therefore, the corrosion rate of the samples in the test can be calculated based on the current and test time in the tests.

The obtained test results and calculated corrosion rate were summarized in Table 3. As shown in the table, 94% of the measured corrosion rate is greater than the calculated value based on Faraday's law, suggesting that the corrosion rate measured in the test tends to be higher.

The maximum difference between calculated and measured results is 4.435%, among which most were less than 2.0%. The relative error (RE), which is the difference between the measured corrosion rate and the calculated corrosion rate divided by the measured corrosion rate, was calculated for each test for comparison. The RE value indicates how much the measured value deviates from the theoretical value. Statistics on the results in Table 3 show that the measured value with an RE from 0 to 10% accounts for more than 74%, indicating that the results calculated based on equation (1) have a high reliability.

3.2. Corrosion Morphology

3.2.1. In the Test. The corroded sample 1.0-2.0-7-0 was taken out from the tank, as shown in Figure 3. The corrosion products attached to the surface of the corroded sample were loose and flaky, which can be peeled off easily. There are multiple holes distributed on the surface. With exposure to the air for a while, the flaky corrosion products began to turn yellow and reddish brown.

The flaky corroded products should be composed of iron oxide and hydroxide. After peeling off the loose and flaky products, it can be observed that a thick layer of dark substance adheres to the surface of the cable sample, which was soft and could be easily scraped off with a blade. A white

tissue was used to wipe the dark material to detect that the color was gray green, indicating that ferrous hydroxide was contained in the dark material, as shown in Figure 4. As the surface product was exposed to the air, its local rust quickly developed, which also proved the existence of ferrous hydroxide. The peeled dark substance has magnetism, so it can be determined that the main component of the dark substance is Fe_3O_4.

The above results showed that the morphology and composition of the corroded products in electrolytic corrosion test were consistent with those of the anchor cables in service [2]. The main difference of the cable corrosion between test and the in-service is the corrosion mechanism. Compared with cable corrosion in natural environment, electrolytic corrosion accelerated the generation of iron ions in the corrosion, and the corrosion process would not be limited by the oxygen content in the electrolyte.

3.2.2. After Removing the Corrosion Products. The rust remover and manual wiping were used to remove the rust from the corroded sample to observe the sample surface, as shown in Figure 5(a). The cable sample was obviously thinner. The corrosion mainly occurred in the outer wires, and the center wire showed slight corrosion. The corrosion of anchor cables in service has the same characteristics. As shown in Figure 5(b), the corrosion of a sample from a power station mainly occurs on the outer wires, and no obvious corrosion was seen on the center wire. Due to the structure of the anchor cable, there are gaps between the wires, which allows the electrolyte flow to the center wire, while the above results indicate that the corrosion of the center wire is very small.

The corrosion sample was cut to observe its cross section, as shown in Figure 6. It could be found that, with the increase of corrosion rate, the cross-sectional area decreases clearly. It can be seen from the cross-sectional images that almost no corrosion occurred in the center wire for any corrosion rate. In contrast, with the increase of corrosion rate, the cross section of the outer wires gradually changed from a round to a fan shape. The cross-sectional shape of different outer wires also varied, which suggested that the corrosion of anchor cable under electrolytic conditions is not strictly uniform. But, as a whole, it can still be regarded as uniform corrosion.

3.3. Effect of Sodium Chloride Concentration.

3.3. Effect of Sodium Chloride Concentration. The 0.2%, 1.0%, 2.0%, and 5.0% (w/w) sodium chloride solutions were chosen in the test. The test results are shown in Figure 7.

The results indicate that the calculated corrosion rate was slightly different from the measured corrosion rate for different sodium chloride concentrations. However, Figure 7(b) implied that there was no consistent regularity between RE and sodium chloride concentration. The absolute value of RE is 15% at the maximum and 3% at the minimum, which did not increase or decrease with the increase of sodium chloride concentration. Each curve also shows no regularity. But the test results of 1.0 A–1 d are more consistent, and the value fluctuates around 5%.

TABLE 2: Summary of anchor cable electrolytic corrosion test.

Test	Current (A)	Sodium chloride concentration (%)	Time (d)	Locked force (kN)
0.1-2.0-7-0	0.1	2.0	7	0
0.2-0.2-1-0	0.2	0.2	1	0
0.2-0.2-7-0	0.2	0.2	7	0
0.2-1.0-1-0	0.2	1.0	1	0
0.2-1.0-7-0	0.2	1.0	7	0
0.2-2.0-1-0	0.2	2.0	1	0
0.2-2.0-7-0	0.2	2.0	7	0
0.2-5.0-1-0	0.2	5.0	1	0
0.2-5.0-7-0	0.2	5.0	7	0
0.5-0.2-1-0	0.5	0.2	1	0
0.5-0.2-7-0	0.5	0.2	7	0
0.5-1.0-1-0	0.5	1.0	1	0
0.5-1.0-7-0	0.5	1.0	7	0
0.5-2.0-1-0	0.5	2.0	1	0
0.5-2.0-5-0	0.5	2.0	5	0
0.5-2.0-7-0	0.5	2.0	7	0
0.5-5.0-1-0	0.5	5.0	1	0
0.5-5.0-5-0	0.5	5.0	5	0
0.5-5.0-7-0	0.5	5.0	7	0
1.0-0.2-1-0	1.0	0.2	1	0
1.0-0.2-5-0	1.0	0.2	5	0
1.0-0.2-7-0	1.0	0.2	7	0
1.0-1.0-1-0	1.0	1.0	1	0
1.0-1.0-5-0	1.0	1.0	5	0
1.0-1.0-7-0	1.0	1.0	7	0
1.0-2.0-1-0	1.0	2.0	1	0
1.0-2.0-5-0	1.0	2.0	5	0
1.0-2.0-7-0	1.0	2.0	7	0
1.0-5.0-1-0	1.0	5.0	1	0
1.0-5.0-3-0	1.0	5.0	3	0
1.0-5.0-5-0	1.0	5.0	5	0
1.0-5.0-7-0	1.0	5.0	7	0
1.0-5.0-5-52	1.0	5.0	5	52
1.0-5.0-5-104	1.0	5.0	5	104
1.0-5.0-5-156	1.0	5.0	5	156

Although the change of sodium chloride concentration may affect the conductivity of the electrolyte, the power supply can still offer a relatively stable current output by adjusting the potential between the two electrodes automatically and eliminate the influence caused by the solution conductivity. In summary, it can be deduced that the change of sodium chloride concentration could not effectively increase or reduce the RE and there is no strong correlation between them. The result dissimilarity indicated by three other test groups might be due to the test errors or other factors.

3.4. Effect of Current. In the electrolytic corrosion test, current I only affects the electrolysis rate in theory. The current of electrolytic test varied for different previous studies. For example, Almusallam et al. [12] chose 0.4 A direct current, while Lee et al. [13] chose 1.0 A current. The determination of current was mostly based on experience and there is no specific reference. The results for different current are shown in Figure 8.

As shown in Figure 8(b), the current has an obvious effect on the RE. With the increase of current, the RE decreases first and then increases. When the current was 0.5 A, the RE is negative; namely, the measured corrosion was smaller than the calculated corrosion. Although it is negative, its deviation is the smallest.

Figure 8(b) suggested that, except for several data, the maximum RE caused by the current is about 20% and the value could be reduced by selecting the appropriate current. The deviation of RE may be because of the instability of the power supply. Firstly, it was difficult for the power supply equipment to reach the preset value accurately and stay constant. Secondly, the current would randomly wave with the development of corrosion during the tests. This randomly changing current would increase the difference between calculated and measured results. However, the test results suggest that choosing an appropriate current in the tests may achieve more stable results.

3.5. Effect of Test Time. Six groups of tests with different sodium chloride solution were conducted to evaluate the effect of test time on the corrosion; the test results were shown in Figure 9.

TABLE 3: Results of anchor cable electrolytic corrosion test.

Test	Sample length (cm)	Calculated corrosion rate (%)	Measured corrosion rate (%)	Relative error (%)
0.1-2.0-7-0	34.30	4.606	5.035	9.39
0.2-0.2-1-0	34.50	1.308	1.554	18.62
0.2-0.2-7-0	34.30	9.212	9.763	5.97
0.2-1.0-1-0	34.50	1.308	1.587	21.38
0.2-1.0-7-0	34.30	9.212	10.099	9.69
0.2-2.0-1-0	34.50	1.308	1.543	17.93
0.2-2.0-7-0	34.40	9.186	9.954	8.44
0.2-5.0-1-0	34.50	1.308	1.557	19.31
0.2-5.0-7-0	34.00	9.294	11.568	24.54
0.5-0.2-1-0	34.50	3.271	3.476	6.34
0.5-0.2-7-0	34.20	23.098	23.595	2.15
0.5-1.0-1-0	34.50	3.271	3.481	6.34
0.5-1.0-7-0	34.20	23.098	26.329	14.01
0.5-2.0-1-0	34.40	3.281	3.587	9.34
0.5-2.0-5-0	34.70	16.261	17.327	6.60
0.5-2.0-7-0	34.10	23.166	22.864	−1.32
0.5-5.0-1-0	34.30	3.290	3.484	6.03
0.5-5.0-5-0	34.70	16.261	18.769	15.47
0.5-5.0-7-0	34.50	22.897	22.120	−3.38
1.0-0.2-1-0	34.40	6.561	6.867	4.67
1.0-0.2-5-0	34.90	32.336	35.332	9.28
1.0-0.2-7-0	34.60	45.663	47.628	4.30
1.0-1.0-1-0	34.50	6.542	6.724	2.75
1.0-1.0-5-0	34.90	32.336	34.072	5.38
1.0-1.0-7-0	34.70	45.531	46.725	2.61
1.0-2.0-1-0	34.40	6.561	7.009	6.87
1.0-2.0-5-0	35.00	32.243	33.502	3.91
1.0-2.0-7-0	34.90	45.270	48.208	6.49
1.0-5.0-1-0	33.00	6.839	7.041	2.90
1.0-5.0-3-0	34.50	19.626	20.959	6.80
1.0-5.0-5-0	34.50	32.711	35.844	9.59
1.0-5.0-7-0	34.50	45.795	50.230	9.68
1.0-5.0-5-52	34.40	32.802	36.118	10.11
1.0-5.0-5-104	34.40	32.802	35.568	8.43
1.0-5.0-5-156	34.30	32.901	36.397	10.63

(a)   (b)

FIGURE 3: Morphology of corroded anchor sample. (a) Loose and flaky corrosion product; (b) distributed holes.

As shown in Figure 9(a), the corrosion rate of the sample is basically linear with time. The test results show that the relative error caused by the test time is less than 10% (see Figure 9(b)). The main causes of RE may be the measurement error, the immersion corrosion of anchor cable in electrolyte, stability of power supply equipment, and so on. Among these factors, the impact of these factors is unrelated to the electrolytic time.

3.6. Effect of Prestress. The anchor cable is prestressed in service. One group test was conducted to analyze the effect of stress on corrosion. The results are shown in Figure 10.

The result depicted in Figure 10 indicates that, for the same current, solution concentration, and test time, the calculated corrosion rate for different stress levels is basically close to the measured value, and the difference
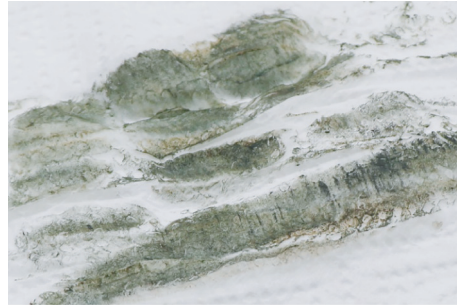
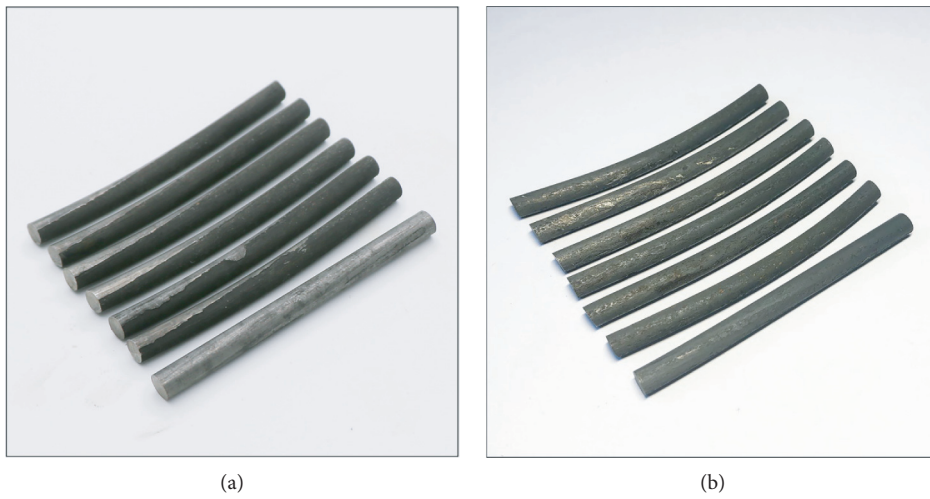FIGURE 4: Corroded products on the surface of the sample.

(a)

(b)

FIGURE 5: Morphology of anchor cable corroded samples. (a) Samples in electrolytic corrosion test; (b) samples from a power station.
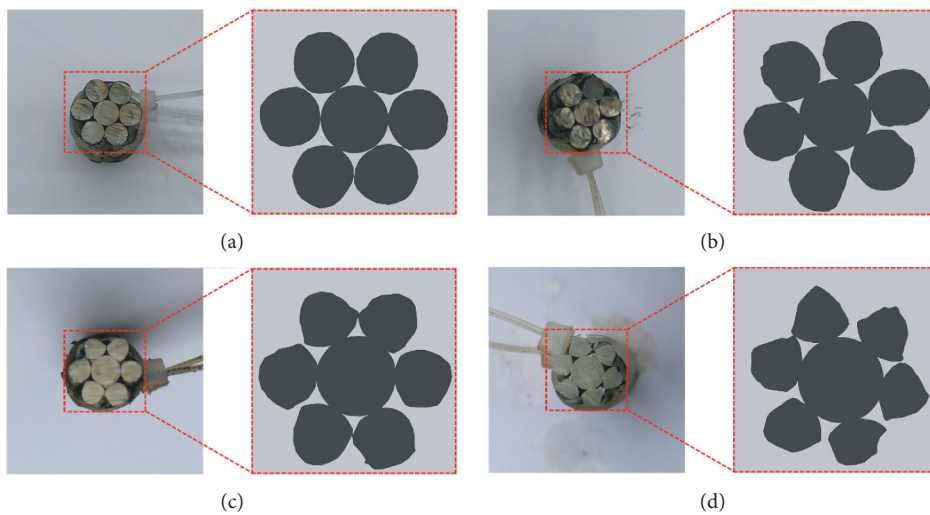

(a)

(b)

(c)

(d)

FIGURE 6: Cross section of corroded samples. (a) corrosion rate 11.57%, (b) corrosion rate 22.12%, (c) corrosion rate 35.84%, and (d) corrosion rate 50.23%.

basically fluctuates around 3.0%. The RE is maintained at around 10% and its variation is small, which indicates that the prestress does not significantly affect the corrosion rate and the RE.

4. Discussion

From the perspective of the corrosion rate of the anchor cable, the actual measured value is generally greater than the
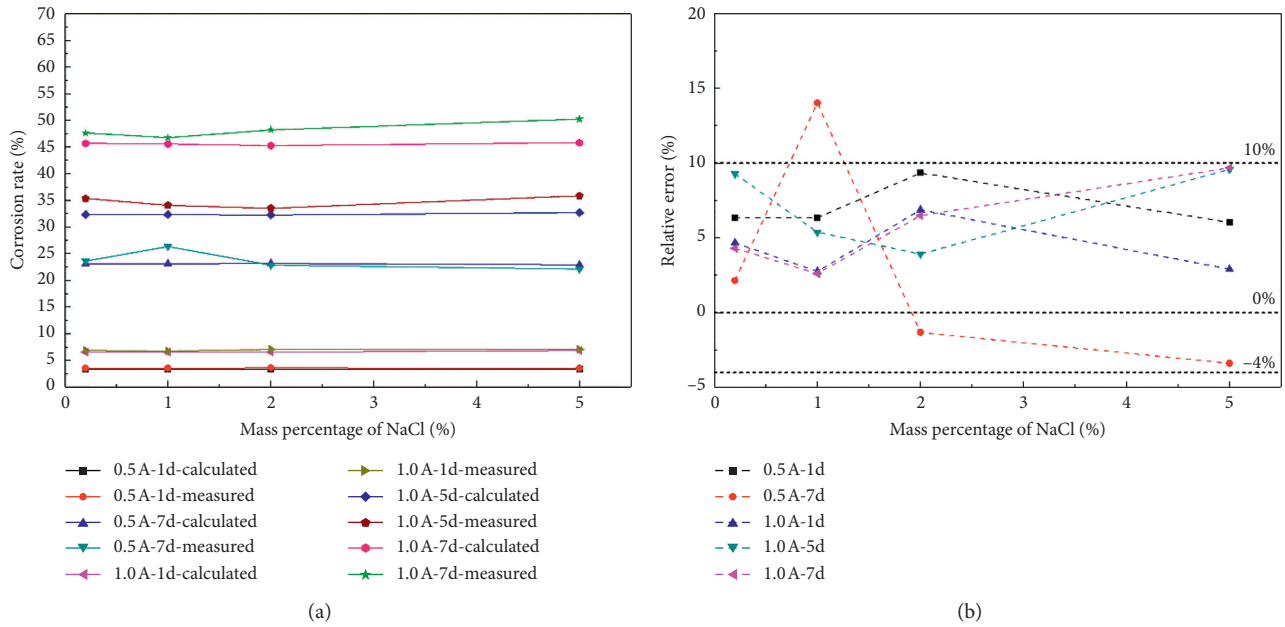
(a)

(b)

Figure 7: Corrosion rate and RE of anchor samples for different sodium chloride concentrations.
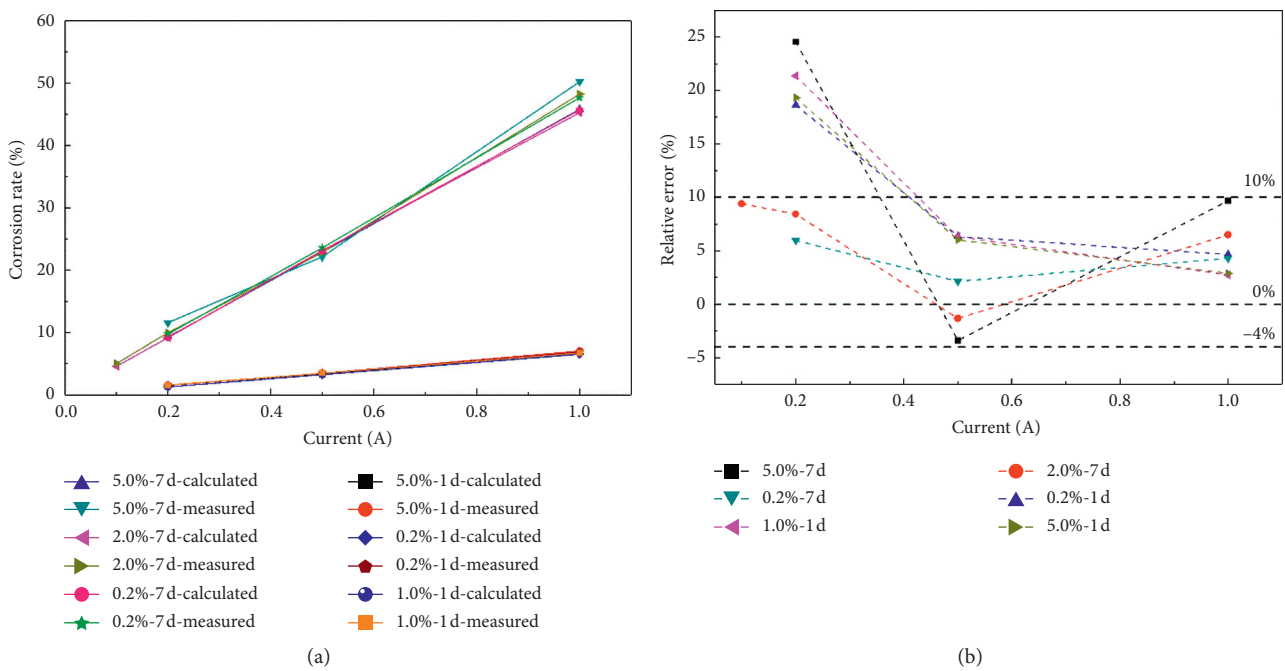

(a)

(b)

Figure 8: Corrosion rate and RE of anchor samples for different currents.

theoretical calculated value. The reason may be that, in the test, in addition to electrolytic corrosion, immersion corrosion inevitably occurred during the corrosion process. Immersion corrosion increases the amount of corrosion of the anchor cable, causing the measured corrosion rate to be greater than the theoretical calculation value based on Faraday's law.

In previous studies conducted with electrolytic corrosion tests, most researchers used sodium chloride solution as the

electrolyte but failed to discuss the effect of Cl^- concentration [10–17]. The Cl^- concentration may affect the conductivity of the electrolyte and the velocity of immersion corrosion of the sample in the solution. First, although the conductivity of the electrolyte will increase with the increase of Cl^- concentration, the constant current is used in the test, and the difference in conductivity caused by the Cl^- concentration can be ignored. Second, the existing researches [19, 20] suggested that Cl^- concentration had an effect on the
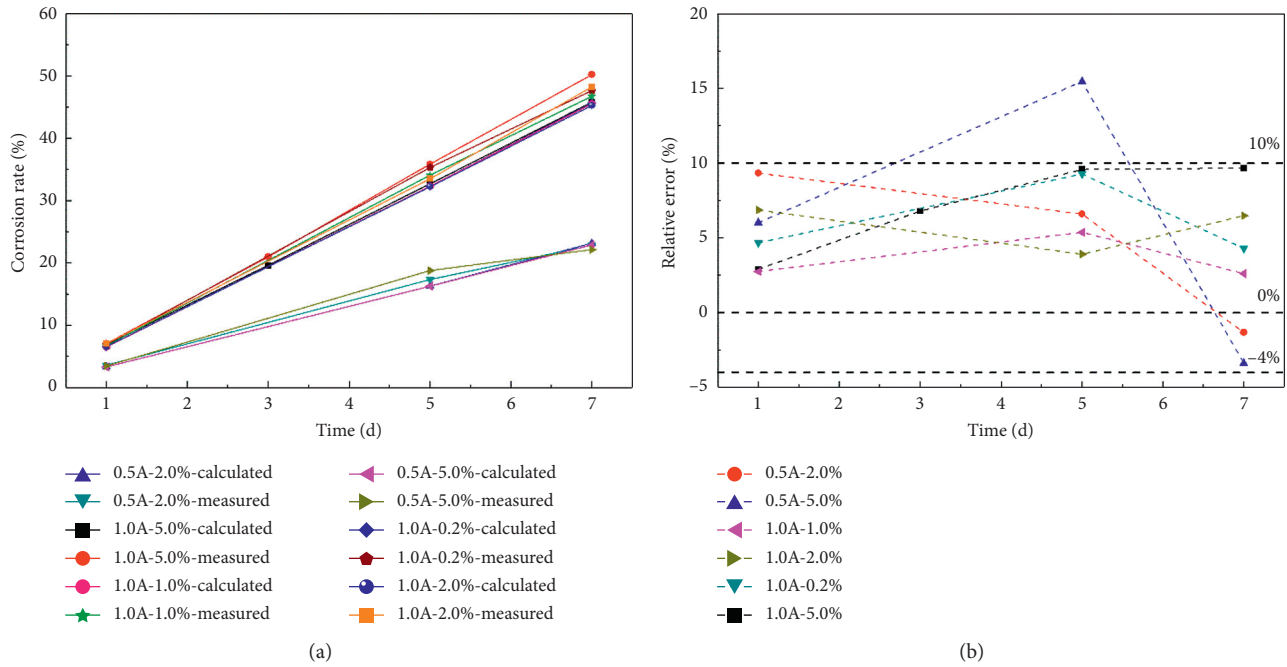
(a)

(b)

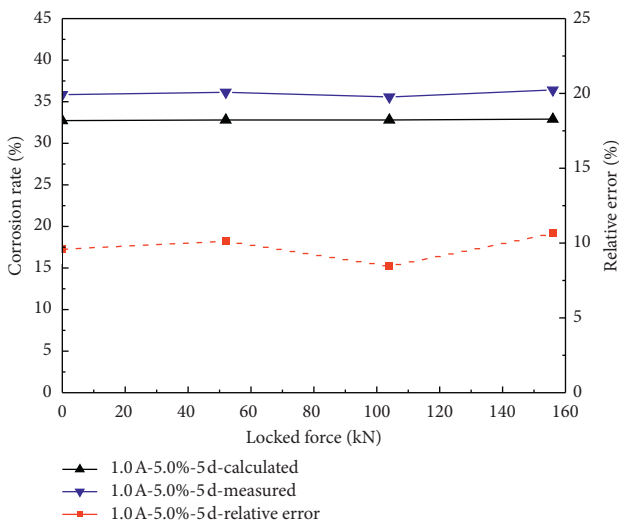FIGURE 9: Corrosion rate and RE of anchor samples for different test time.

FIGURE 10: Corrosion rate and RE of anchor samples for different locked forces.

immersion corrosion of steel. Xu et al. [20] used the immersion test method to study the effect of Cl⁻ concentration on the corrosion of steel and found that, with the increase of Cl⁻ concentration, the corrosion rate of steel increases at the beginning and then decreases, with a maximum of 0.12 mm/a. Compared with the case where the Cl⁻ concentration is 0, the maximum increase in corrosion rate caused by the increase of Cl⁻ concentration is 0.02 mm/a. The reason for the decrease in corrosion rate is that the increase in Cl⁻ concentration causes the decrease of the dissolved oxygen in the solution, and other studies also support this point [19]. But, even for the maximum corrosion rate reported by Xu et al.

[20] and the maximum designed test time of 7 days in this test, the increase of the corrosion rate caused by the Cl⁻ concentration is only 0.0024 mm/7 d. Compared with the results of the electrolytic corrosion test, the corrosion variation caused by the Cl⁻ concentration is negligible. Moreover, in the electrolysis test, the amount of iron ions generated by the applied current is extremely plentiful, and the oxygen consumption in the solution is extremely large. Therefore, the oxygen content of the solution in electrolytic corrosion is extremely low, and the effect of Cl⁻ concentration on the corrosion rate of steel will be smaller. Based on the test results, it could be concluded that the influence of sodium chloride concentration on the electrolysis results could be ignored when the sodium chloride concentration is less than 5.0%. This could provide a reference for the selection of sodium chloride concentration in the future electrolytic test.

According to Faraday's law, for a certain length of sample, the corrosion is linear with current. However, the corrosion rate of the anchor cable sample with small current is much smaller than that with large current. Therefore, the sample corrosion caused by immersion corrosion accounts for a relatively large contribution to the final corrosion result, so it is more likely to increase RE. This also explains the results that the RE of some test results with small current exceeds 10%, as shown in Figure 8(b). Second, the instability of the power supply device in the test may also be one of the reasons. The test results showed that, for the constant current power supply, choosing a moderate current value will help to obtain relatively stable results. In summary, when the calculation result of corrosion rate based on Faraday's law needs to be used to calibrate the results of the anchor cable in the test, a smaller current is not a wise

choice. On the other hand, according to the research of Almusallam et al. [12], the establishment of a check curve of the relationship between the corrosion rate and the test time under different current conditions can also minimize this effect caused by the power supply device and the immersion corrosion.

It is generally believed that the influence of stress on steel corrosion can be divided into two types: one is the stress corrosion cracking under the combined action of corrosion and stress, and the other is the effect of stress on the metal corrosion rate. The SCC is not a problem involved in this paper. For the second, Li et al. [21] pointed out that stress will accelerate the corrosion of steel, since the tensile stress will cause a negative increase in the anode equilibrium potential, which makes corrosion easier to occur. However, the potential fluctuation caused by this stress is very small, and the corresponding corrosion amount is little. Considering that the test period is short, the effect of prestress is difficult to reflect in the test results. Thus, it can be considered that the influence of prestress can be ignored in the electrolytic test. This is also proved by the results of the electrolytic test.

Although the electrolytic corrosion test was widely used in the research of reinforced concrete, the applicability of the electrolytic corrosion test is controversial. Li et al. [21] pointed out that the electrochemical mechanism, corrosion morphology, corrosion products, mechanical properties, and bonding properties of corroded steel bars in the test are different from samples of the actual structure. Yuan et al. [22] compared the artificial climate corrosion test and the electrolytic corrosion test in the study and concluded that the artificial climate corrosion is more similar to the corrosion of steel in environment. Zhang et al. [23] also pointed out that the electrolytic corrosion of steel is different from corrosion in environment in terms of corrosion characteristics and postcorrosion mechanical properties. But they believed that the electrolytic corrosion test can better show the tendency of structural deterioration caused by corrosion. For anchor cables, the controversy mainly focuses on the corrosion mechanism, products, and morphology. First, the electrolytic corrosion and the corrosion in environment are obviously different. Although both types of corrosion are electrochemical, the latter is a reaction in corrosion cell, while the former is a corrosion reaction under applied current. Second, the corrosion products are also different. Zhang et al. [23] believed that this difference is caused by insufficient oxygen in the electrolyte, which is consistent with the results of this test. For the corrosion in environment of anchor cable, due to the slow reaction rate, the ferrous ions in the corrosion products can be fully oxidized to form relatively stable oxidation products on the surface. However, in electrolytic corrosion, the dissolved oxygen in the electrolyte is quickly consumed because of the high ferrous ion generation rate, which may cause the inability of most of the ferrous ions to be fully oxidized. With the supplement of dissolved oxygen in the electrolyte, the corrosion products on the surface of the anchor cable are gradually oxidized, forming a stable oxidation product finally. Therefore, the corrosion products of the two are the same finally. Third, for

corrosion morphological characteristics, the corrosion of steel in the presence of chloride ions is characterized by pitting corrosion but in electrolytic corrosion is closer to uniform corrosion. But it should be noticed that the pitting corrosion characteristics were mainly observed at a lower corrosion rate. The corrosion morphological characteristics of the anchor cable at the high corrosion rate as in the electrolytic corrosion test have not been reported. Thus, to evaluate the applicability of the electrolytic corrosion test based on the corrosion morphological characteristics is not rational. The test results of anchor cable in electrolytic corrosion show that the corrosion mainly occurs on the outer wires. The center wire has little corrosion. This is consistent with the corrosion of the anchor cable in service. This may help to provide support for the applicability of electrolytic corrosion method in the research of anchor cable corrosion. Hence, assuming that the corrosion of the anchor cable is uniform, it can be considered that the electrolytic corrosion test is suitable for the anchor cable corrosion study.

For now, the relatively successful application of the electrolytic corrosion method is to use the EC test to assess the corrosion resistance of the Cu-Ni-Cr coating [24–26]. For the specified test conditions, the sample obtained by the electrolytic corrosion test is more consistent with the actual service sample, and then this method was established as an international standard [24]. Later, Lu et al. [27] proposed a method for predicting the corrosion state of steel bars in natural environments based on the results of electrolytic corrosion tests by studying the relationship between electrolytic corrosion and dry and wet corrosion in chloride solution of steel bars. These studies provide a broader field for the applicability of the electrolytic corrosion test.

5. Conclusion

In this paper, the electrolytic corrosion tests of anchor cables in different sodium chloride concentration solutions and with varied stress levels were conducted to investigate the corrosion laws and morphology. The applicability of electrolytic accelerated corrosion test in the anchor cable corrosion research was evaluated. In the test, with the increase of the anchor cable corrosion, the central wire of the cable basically does not corrode, and the cross-sectional shape of the outer wire changes from a circle to a fan shape, which provides a reference for related analysis based on the aspect. The corrosion of the anchor cable conforms to Faraday's law and the corrosion rate of the anchor fluctuates from −4% to 10% compared with calculated results based on Faraday's law. The results show that the sodium chloride concentration and prestress level have no obvious effects on electrolytic corrosion. A proper current can help obtain a more reasonable corrosion rate in the electrolytic corrosion test. The variation of test time does not affect the difference between the measured and theoretical calculated results. In general, it is feasible to use the electrolytic corrosion test in the anchor cable corrosion study. The method is efficient and controllable.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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