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Retraction

Retracted: Durability Test and Mechanical Properties of CFRP Bolt under Accelerated Corrosion Conditions

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] Q. Li, X. Li, and L. Guo, "Durability Test and Mechanical Properties of CFRP Bolt under Accelerated Corrosion Conditions," *Journal of Chemistry*, vol. 2022, Article ID 2094640, 7 pages, 2022.

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Research Article

Durability Test and Mechanical Properties of CFRP Bolt under Accelerated Corrosion Conditions

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In order to study the influence of acid corrosion on the quality, elastic modulus, tensile strength, elongation, and other properties of epoxy mortar test block and CFRP bolt, the durability test and mechanical properties test of CFRP bolt under accelerated corrosion conditions were proposed. An epoxy mortar test block was soaked in acidic solution for 90 d, and the quality, elastic modulus, tensile strength, elongation, and other properties of CFRP bolt were analyzed. Through the analysis of test data, the load-slip relationship curve of bolt was obtained and the Arrhenius equation was used. The relationship curve between tensile strength retention and logarithm of time in test environment was obtained, and the concept of conversion factor TSF was introduced to predict the strength retention of anchor corroded by acid rain for 20 years in service. The experimental results show that the maximum loss rates of mass, elastic modulus, and compressive strength of epoxy mortar test block are 1.98%, 2.81%, and 11.25%, respectively, during 90 d immersion in acidic solution. The maximum loss rates of mass, elastic modulus, tensile strength, and elongation of CFRP bolt are 0.65%, 3.29%, 6.51%, and 5.06%, respectively. Based on the analysis of the test data, the load-slip curve of the bolt is obtained, which indicates that acid corrosion reduces the bond performance of CFRP bolt. The bond-slip curve of bolt after 90 d acid corrosion was obtained by further analysis of experimental data. *Conclusion*. The experiment has certain engineering application values.

1. Introduction

Anchor rod is the rod system structure of rock and soil reinforcement. It uses an anchor rod body to exert longitudinal tension on rock and soil mass to overcome the shortcoming that the tensile capacity of rock and soil mass is far lower than the compressive capacity. Bolt anchoring is an important field in civil engineering. In geotechnical engineering, bolt anchoring can reduce the size and weight of the structure. It greatly improves the strength and stability of the rock and soil structure and effectively reduces the deformation of rock and soil structure. In 1912, the bolt was first used in the support of coal mine tunnel in Scheretz Mine in Germany, which opened the era of the use of bolt in civil engineering.

At present, the United States, Europe, and Japan have taken the anchor as an important means of underground excavation engineering construction. The number of bolts in use is more than 500 million every year and the usage is increasing year by year. Foreign bolt manufacturers led by Henkel and Firep export a large number of rock and soil bolts to emerging regions such as South America and Asia, and the export volume is also increasing year by year [1]. In recent decades, rock and soil anchoring technology has been greatly developed in China, and many new theories and technologies have been put forward, which are widely used in civil engineering construction such as slope, foundation pit, dam, waterway, mine and airport, and many bolt production companies with independent intellectual property rights have emerged. With the construction of infrastructure in China, especially water conservancy, transportation, energy, and urban infrastructure construction, rock and soil anchorage will show a broad development prospect. In the process of use, materials are affected by the environment and their performance degrades, their state changes, until they are damaged and deteriorated, which is usually called corrosion

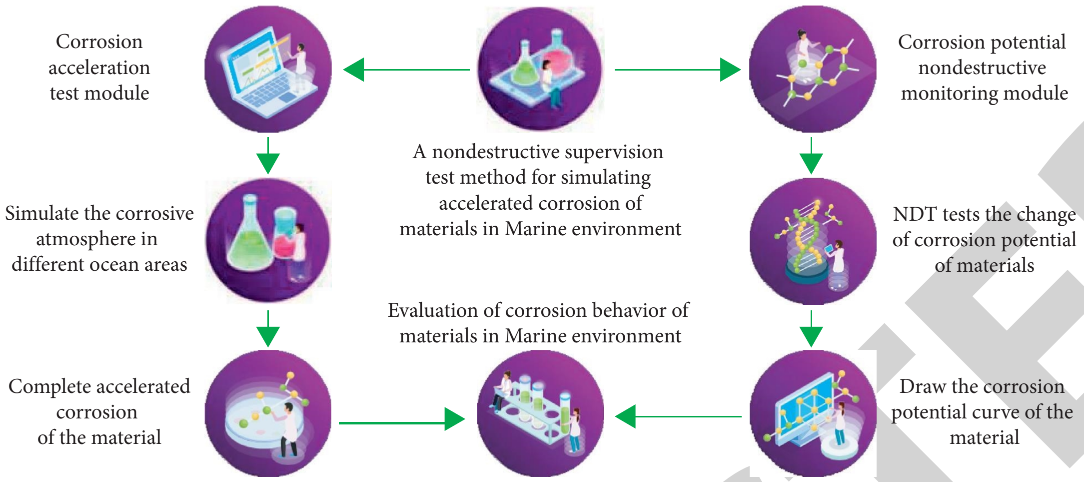

Figure 1: CFRP anchor.

[2]. Material corrosion not only brings great economic loss and a large amount of resources and energy consumption to the country but also threatens equipment, equipment, buildings, and personal safety.

We carry out corrosion tests of materials, accumulate corrosion data, and combine with laboratory analysis and research, which is of great significance to control the natural environment corrosion of materials and to provide scientific basis for the research and development of new materials, especially for the rational selection of materials, the adoption of corresponding protection measures, and the assurance of engineering quality and reliability for national key engineering construction and national defense construction, as shown in Figure 1:

2. Literature Review

Krishnadasan et al. conducted temperature cycling and humidity exposure tests on carbon fiber sheets and glass fiber sheets in 1997, and the results showed that the tensile strength, elastic modulus, and ultimate strain of CFRP are not decreased but increased, and the interface between the carbon fiber and epoxy composites is damaged and the bond between the fiber and matrix is reduced. After temperature cycling, the tensile strength and elastic modulus of GFRP do not decrease, but the ductility decreases and the embrittlement trend occurs. Under the condition of humidity exposure, the tensile strength of GFRP decreases obviously. After temperature cycling, the tensile strength and elastic modulus of epoxy resin are improved, but under humidity, the tensile strength and elastic modulus decrease significantly [3]. Yang et al. in 1994 studied the durability of reinforced concrete beams externally reinforced with aramid fiber, E-glass fiber, and graphite fiber fabrics under freeze-thaw and dry-wet cycles. The results show that the reinforced beams with aramid, E glass, and graphite are degraded in different degrees and their ultimate strength is reduced. The strength advantage of aramid and E-glass reinforced beams is almost invisible, with a loss of one-half, but graphite still retains the advantage and the strength loss is not large [4]. In 1997, Liu et al. studied the effects of FRP sheets on the performance and bond properties of concrete beams reinforced with FRP sheets in a saline dry-wet cycling environment. The research results show that the bearing capacity of FRP externally pasted concrete beams is improved when subjected to tensile surface, and the durability of the binder has a great influence on the durability of FRP reinforced concrete [5]. Castillo et al. conducted an experimental study on the dry-wet cycle and freeze-thaw cycle durability of CFRP- and GFRP-reinforced concrete cylindrical structures in salt water. The results showed that the strength, ductility and stiffness of CFRP reinforced specimens decreased under the dry-wet cycle. The strength, ductility, and stiffness of GFRP-reinforced specimens are reduced. The strength and ductility of both are reduced and the stiffness is basically unchanged under freeze-thaw cycles. However, in general, CFRP- and GFRP-reinforced structures still show good performance in harsh environment, and the effect of freeze-thaw cycle is greater on CFRP and GFRP than that of the dry-wet cycle [6]. Elgohary et al. simulated the long-term working environment around concrete beams repaired by FRP through the short-term acceleration test. During the simulation process, the specimens were soaked in boiling water and irradiated by an ultraviolet lamp for seven days. The test structure showed that the efficiency of FRP reinforcement could be reduced by more than 50% and the stiffness could be reduced by nearly 50% under harsh environment conditions. The superiority of CFRP reinforcement is reduced. The leading role of the FRP polymer matrix on the long-term performance of FRP is proposed [7]. Nabipour and Akhoundi mainly studied the overall durability of CFRP-reinforced structures from the durability of CFRP and the durability of the bond between CFRP and concrete. The research structure shows that the bond performance between CFRP and concrete is improved under ultraviolet and water leaching environment conditions [8]. Memon et al. conducted repeated freeze-thaw cycle tests on concrete members reinforced by fiber materials. The effect of the freezing-thawing cycle on the durability of a bond interface was studied by comparing with the reinforced system in a common environment. In addition, they analyzed the changing trend of interface bond strength and initial cracking load with the increase of freezing-thawing cycles, studied the damage mechanism of new and old concrete bond surface, and gave suggestions for bond repair of concrete structures damaged by freezing-thawing. It provides a theoretical basis for structural reinforcement in cold regions [9].

FRP bars have high tensile strength and corrosion resistance, light dead weight and easy construction, so since the 1990s, FRP bars have been used in engineering and replaced steel bolts [10]. At present, the widely used FRP bars mainly include CFRP, AFRP, GFRP, and so on. The working environment of the anchor bolt is relatively bad, such as the erosion of anchor bolt by acid rain, electrochemical corrosion of sodium and calcium salt in rock and soil, etc., which will affect the safety of the use of the anchor bolt. Based on the durability test research of CFRP bolt in an acidic corrosion environment, there are still few relevant research studies in China [11]. The test of the CFRP bolt in an acidic corrosion environment was carried out by using the method of high concentration solution acceleration. The test results have certain guiding significance for the design and engineering application of the CFRP bolt.

3. Research Methods

3.1. Test Materials and Equipment. CFRP bolt: 7 mm diameter light round steel bar produced by a company is used in the test, and the length of anchor is 245 mm, 300 mm, and 350 mm.

Epoxy mortar test block: the main components are epoxy resin + curing agent + filler, curing agent, and filler are mixed in a certain proportion, and the epoxy mortar test block is made according to the requirements of GB 50203-2011 Code for Construction Quality Acceptance of Masonry Structure Engineering. The tensile test equipment is a hydraulic universal testing machine.

3.2. Test Method. In this corrosion test, 98% concentrated sulfuric acid was diluted to design a strong acid environment with pH = 3. In order to avoid corrosion of the immersion container, a PEVA corrosion resistant material was used to seal the immersion container with multiple layers. Butter the surface of the anchor before soaking to avoid serious corrosion of the anchor that would affect the mechanical properties of the test. On the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th days, the physical properties such as mass and size were measured. We test the pH of the soaking solution once a week to ensure that the pH is constant. Mechanical properties of the epoxy mortar test block and bolt were tested on an universal testing machine without soaking and after soaking for 30, 60, and 90 days [12]. The compressive strength of the epoxy mortar block was tested by a compressive failure test and its elastic modulus was calculated by stress and strain. The tensile strength of the CFRP bolt was tested by tensile failure test, and its physical properties such as elongation and elastic modulus were calculated by test data. Finally, the bond performance of bolt is analyzed by test data.

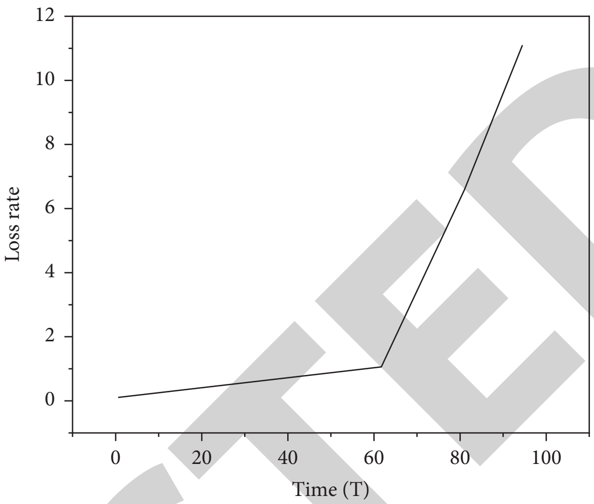

FIGURE 2: Loss ratio of performance index of the epoxy mortar test block in an acid corrosion process.

4. Result Analysis

4.1. Epoxy Mortar Test Block. During the test, the change of the outer color of the test block cannot be observed with the naked eye. When it was taken out every 10 days, there were water drops on the surface of the test block, indicating that the immersion solution only eroded its surface and failed to erode into the inside of the test block [13]. It can be seen that the epoxy mortar test block has good compactness inside, and the adhesive layers can be tightly cemented. In the test process, performance index loss of epoxy mortar test block is shown in Figure 2.

It can be seen from Figure 2 that the mass loss of epoxy mortar test block is small, and the mass remains basically unchanged 30 days before the test, with the maximum mass loss rate of about 1.98%. The elastic modulus changed little during the test, and the maximum loss was about 2.81%. The compressive strength changes slightly in the first 60 days, and the maximum loss rate is 11.25% from the 60th day to the 90th day.

4.2. CFRP Anchor. The loss rate of surface performance index of CFRP bolt during acid corrosion process is shown in Figure 3.

As can be seen from Figure 3, after soaking for 30 days, the quality of the CFRP bolt is basically unchanged, but a protective layer has been formed on its surface, so it can be considered that corrosion has not started yet. After soaking for 60 days, the protective layer coated on the bolt has disappeared, and the anchor has corrosion phenomenon, but the reinforcement has no corrosion phenomenon, and the quality is reduced compared with that before 30 days. After soaking for 90 days, the corrosion of anchor is further aggravated, and the reinforcement appears swelling. Compared with soaking for 60 days, the mass of anchor increases,

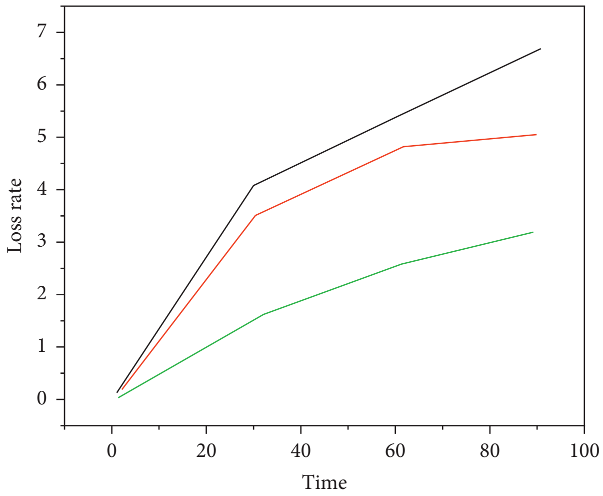

Figure 3: Performance index loss rate of the CFRP bolt in an acid corrosion process.

which can be interpreted as the corrosion liquid has penetrated into the interior of anchor from its surface, resulting in an increase in its mass [14, 15]. In the process of acid corrosion, the mass loss of bolt is small, and the maximum mass loss rate is about 0.65% on the 60th day. The loss rates of elastic modulus, tensile strength, elongation, and other indicators increased with the extension of soaking time. On the 90th day, the maximum loss rates of the above three physical performance indicators were 3.29%, 6.51%, and 5.06%, respectively.

4.3. Bond Slip Change of the CFRP Bolt. The total displacement of the bolt and the elastic deformation of THE CFRP rod are calculated through the test, and the difference between them is the slip of the bolt. The load-slip relationship curves of anchor bolts were drawn (see Figure 4) when they were not corroded by acid, corroded for 60 days, and corroded for 90 days.

It can be seen from Figure 4 that, under the same load, the rock bolt with 90 d acid corrosion has the largest slip, followed by the rock bolt with 60 d acid corrosion, and the minimum is the rock bolt without corrosion [16]. It can be seen that the bond slip of the CFRP bolt increases with the progress of corrosion test, and acid corrosion has a negative effect on its bond performance.

4.4. Fitting of Bond-Slip Curve for 90 d Acid Corrosion. The bond stress-slip curve of three anchorage lengths after acid corrosion for 90 d was sorted out and fitted. The curve fitting equation was as follows

$$\tau = 0.004S^4 - 0.0688S^3 + 0.3358S^2 + 0.8776S + 0.005. \quad (1)$$

The correlation parameters of linear regression can be obtained from equation (1), among which, correlation coefficient $R = 0.992$ and determination coefficient $R^2 = 0.984$. Figure 5 shows the comparison between the test curve and the fitting curve in an acidic environment.

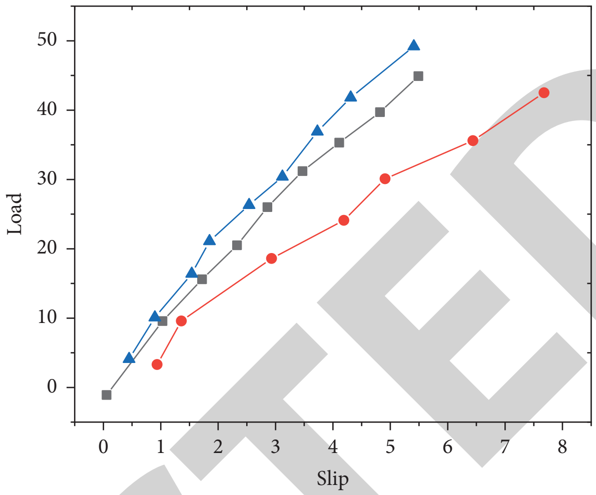

Figure 4: Load-slip curve of acid corrosion.

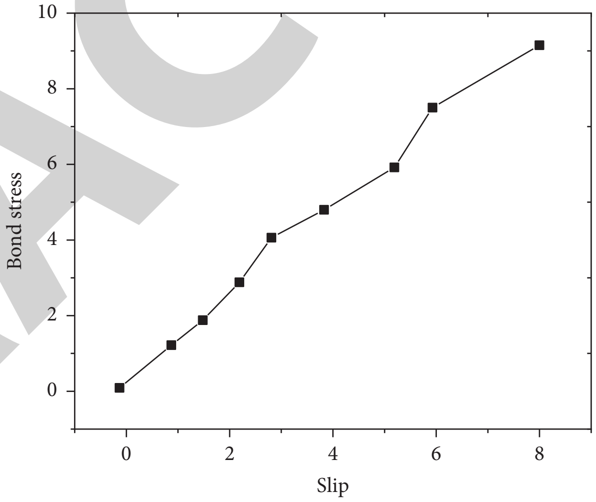

Figure 5: Comparison curve of fitting between the test curve and acid environment.

The results in Figure 5 are used to compare bolts with 245, 300, and 350 mm anchor lengths, and the errors are all within 10%. The pseudosynthetic results can be used to predict the slip values of CFRP bolts with arbitrary anchorage length and diameter under the same acidic environment and different loads.

4.5. CFRP Bolt Working Life Prediction

4.5.1. Arrhenius Equation. Arrhenius equation is the most commonly used method to predict the long-term service life of CFRP bolt using short-time test data. According to the Arrhenius equation, the degradation rate of tensile strength of CFRP bolt in the acidic corrosion environment is shown in equation (2)

$$k = \frac{\mathrm{d}f}{\mathrm{d}t} = A\exp\left(\frac{-E_\alpha}{RT}\right). \quad (2)$$

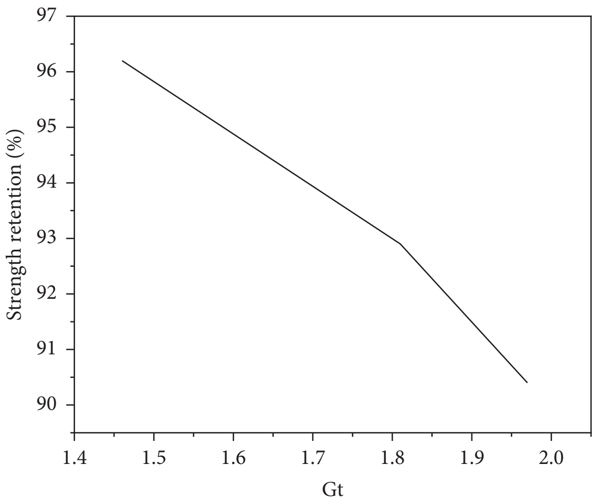

Figure 6: Logarithmic relationship of tensile strength retention rate of the CFRP bolt with time.

Among which, k is the degradation rate of tensile strength of CFRP bolt; f is the tensile strength of CFRP bolt; t is the time. AA are the constants related to material properties; E_α is the activation energy leading to degradation of tensile strength of the CFRP bolt; RR is the molar gas constant, 8.3145 J/(mol·K); and T is the absolute temperature, K.

The FHWA method given by the Federal Highway Administration of the United States is a life prediction method based on Arrhenius equation (see Formula (3)). Many researchers have also shown through experimental studies that the retention rate of tensile strength of bolt Rt basically maintains a linear relationship with the logarithm of time [17]. As the Figure 3 shows

$$R_t = a\lg t + b, \tag{3}$$

where R_t is the retention rate of tensile strength of CFRP bolt, (%); tt is the time; and a, b are constants.

The loss rate of tensile strength of CFRP bolt in Figure 6 can be transformed into the retention rate of tensile strength, and the values of a and b can be obtained by curve fitting according to the least square method. The fitting curve is shown in equation (4).

$$R_t = -6.927\lg t + 106.5. \tag{4}$$

According to equation (4), the regression correlation coefficient $R = 0.996$, and the determination coefficient $R^2 = 0.992$.

Relevant studies show that the Arrhenius equation can be introduced into the concept of conversion factor TSF to calculate the time required for CFRP bolt corrosion to the same degree at two different temperatures [18]. The conversion factor is further studied, and the conversion factor model with pH value as a parameter is established through experiments, as shown in equation (5)

$$TSF = e^{A}\left(10^{-\mathrm{pH1}} - 10^{-\mathrm{pH0}}\right), \tag{5}$$

where TSF is the conversion factor; A is the undetermined coefficient can be obtained from the test; e is the natural constant; and $10^{-\mathrm{pH}}10^{-\mathrm{pH}}$ is the corresponding pH value solution hydrogen ion concentration.

Table 1: Average annual pH value of rainfall in a province in recent 5 years.

Year	In 2011	In 2012	In 2013	In 2014	In 2015
pH value	4.81	4.50	4.52	4.76	4.57

Table 2: Strength retention rate prediction of bolt after service life by Arrhenius.

Acid rain erosion time/year	1.82	3.63	5.45	10.00	20.00
Convert to soak time/d in the test environment	30	60	90	165	330
Anchor strength retention rate/(%)	96.2	94.35	92.85	91.14	88.56

According to the results of this study, $TSF = 1$ when $\mathrm{pH} = 3$; $TSF = 1.459$ when $\mathrm{pH} = 4.5$. The tensile strength loss of bolt soaked in $\mathrm{pH} = 3$ for 90 d was 6.51%, corresponding to the soaking days of bolt soaked in $\mathrm{pH} = 4.5$ with 6.51% loss of tensile strength was $90 \times 1.459 = 131.31$ d.

4.5.2. Influence of Acid Rain on Durability of the CFRP Bolt.

As a large amount of carbon dioxide in nature is soluble in water, the pH value is about 5.6 when the solution reaches gas-liquid equilibrium. Therefore, when the pH value of rainfall is less than 5.6, it can be defined as acid rain [19]. Acid rain has become one of the serious environmental problems in China. The average annual pH value of rainfall in a province in recent five years is shown in Table 1, in which the average annual pH value of acid rain in a city is close to that in a province. The basic pH value of acid rain in a city is 4.5 [20–22].

Relevant data show that the average number of rainfall days in a city from 1951 to 2007 is 144.58 d. Considering that CFRP bolts cannot be dried immediately after rainfall, it is assumed that CFRP bolts are corroded by acid rain for 4 h on average every day during the 144.58 d. It is equivalent to soaking CFRP bolts in $\mathrm{pH} = 4.5$ solution 578.32 h a year, soaking 90 d in $\mathrm{pH} = 4.5$ solution is equivalent to 5.449 years of acid rain erosion of exposed CFRP bolts in a certain area. After 20 years of acid rain erosion, the strength retention rate was 88.56% (see Table 2). It is consistent with the research in literature that CFRP bolts have good acid corrosion resistance, and CFRP bolts are slightly corroded in an acid rain corrosion environment [23–25].

5. Conclusion

The following conclusions were obtained from the study:

(1) The size and appearance color of the epoxy mortar test block did not change significantly during 90 d immersion in acidic solution. The mass, elastic modulus, and compressive strength decreased, and the maximum loss rate was 1.98%, 2.81%, and 11.25%, respectively. With the extension of soaking time, the compressive strength loss of the epoxy mortar test

block is large, and the acid corrosion environment for a long time will have a significant adverse effect on the epoxy mortar test block.

(2) The size and appearance color of the CFRP bolt do not change significantly during 90 d immersion in acid solution. The maximum mass loss occurred on the 60th day and the mass loss rate was 0.65%. The maximum loss rates of elastic modulus, tensile strength, and elongation were 3.29%, 6.51%, and 5.06%, respectively, on the 90th day. The test results show that the decrease of the above physical properties is small, and the acid corrosion resistance of the CFRP bolt is good.

(3) According to the load-slip relationship curve of the bolt, the bond slip of CFRP bolt increases with the progress of corrosion test, and acid corrosion has a negative effect on its bond performance.

(4) The bond slip curve was fitted after 90 days of acid corrosion. The fitted curve can reflect the change of bond performance of the CFRP bolt and epoxy mortar after acid corrosion. The test curve has certain engineering application value and can provide reference for revising related engineering specifications.

(5) Using the Arrhenius equation, the relationship curve between the tensile strength retention rate and logarithm of time in test environment was obtained. By introducing the concept of conversion factor TSF, the experimental environment was converted to an acid rain erosion environment, and the strength retention rate of anchor corroded by acid rain for 20 years was predicted.

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.

Acknowledgments

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