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Research Article

Influence of Corrosion and Fatigue on the Bending Performances of Damaged Concrete Beams

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The durability of in-service reinforced concrete bridges will be greatly reduced under the action of corrosion and the repeated load such as vehicles. In this paper, six reinforced concrete beams were cast and subjected to sustained load test for one year, and then, the alternating test of corrosion and fatigue load were carried out with the damaged concrete beams. The long-term deflection, fatigue lifetime, failure modes, and crack growth were investigated under different corrosion and fatigue working conditions. The fracture section of steel bars was scanned by electron microscopy at the end of fatigue test. The results indicate that the deflection of the beams will continue to increase under a long-term load. The chloride salt in the beam has little influence on the deflection performance, but will shorten the fatigue lifetime due to the corrosion of the steel bars. Moreover, the corrosion environment can accelerate the rusting of the beam bar and reduce the fatigue lifetime, the accumulation of deflection damage and crack damage, and other fatigue characteristics. The crack initiation-propagation-fracture stage of steel bars occurs in the process of fatigue.

1. Introduction

Highways and railway bridges in coastal areas often bear the combined action of both complicated loads and corrosion environments, so their durability problems are increasingly outstanding [1, 2]. In-service concrete bridges usually work with cracks under long-term loads; in this case, the stiffness is decreasing, and the deflection is increasing [3, 4]. At the same time, due to various deterioration effects such as salt damage and freezing damage, corrosion of steel bars is accelerated [5, 6]. Particularly, the rapid growth of traffic and widespread overload of freight make the repeated fatigue effect of vehicle load more and more significant. Some structures, such as high-way or railway bridges, are subjected to cyclic loading over service time and the repeated stress may result in fatigue damage of materials, which will shorten the service life of concrete structures [7, 8]. Therefore, the durability of RC structures under the effects of corrosion and fatigue has always been a popular and important topic in the civil engineering community.

The bulk of the relevant literature about effect of loading and environments on the RC structures includes two aspects mainly. On the one hand, studies mainly investigated the effects of sustained service loads and steel corrosion on the performance of RC structures. The corrosion rate of reinforcements, cracking behavior, chloride permeability, load-deflection curve, flexural stiffness, load-carrying capacity, residual flexural capacity of RC beams under various levels of sustained loading, and corrosion environments were studied [9–14]. On the other hand, studies on the interaction of cyclic load and corrosive environment have mostly focused on the fatigue properties of reinforced concrete beams with corroded steel bars or coupling a corrosive environment and fatigue loading. In most studies, steel bar corrosion that occurred in RC beams was accelerated by electric current, and then, the fatigue tests were carried out on the beams after the steel bars were rusted. This study mainly discussed the effects of different reinforcement corrosion and fatigue loading on the fatigue life, failure modes, crack patterns, and flexural behavior of RC beams [8, 15–22]. Ahn and Reddy [15] simulated the tidal environment by alternately filling and draining while accelerating steel bar corrosion by using the galvanostatic technique. They found that this loading accelerated the corrosion and that the durability of the RC decreased as the concrete water-cement ratio increased. Yi et al. [16] accelerated the corrosion of steel bars in RC beams by first using the galvanostatic technique and then applying the fatigue load and found that the corrosion of steel bars reduced the fatigue life of RC beams. The same method was used by Oyado et al. [17] to accelerate the corrosion of steel bars. The results show that the crack pattern of the corroded tested beam was different from those of the reference beams, and the fatigue strength decreased in proportion to the weight loss of the steel bar due to corrosion. Shang and He [18] accelerated steel bar corrosion to cracking and then carried out fatigue shear tests on uncorroded and corroded RC beams, respectively. The results showed that when the bond action between the steel bars and concrete was damaged by corrosion, the fatigue property of the beam attenuates rapidly.

There are few studies on the coupling effect between fatigue load and corrosive environment. In these studies, the experiment in which the fatigue load was applied to the beams while the steel bar was corroded was carried out mainly, and the steel bar corrosion method included accelerated corrosion by electricity or chloride salt immersing [23–26]. In most of the studies, the corrosion of steel bars was accelerated by the galvanostatic technique, but the electrochemical corrosion process used in this method is not identical to that under natural conditions. Research shows that the corrosion characteristics of RC beams accelerated by the artificial climate exposure method are closer to the ones corroded in natural environments, in comparison to the galvanic method [27]. In addition, because of the complexity of the environment and load, concrete bridges experiences different damages in the service stage. However, researching on the fatigue performance of damaged concrete beams is rare. He et al. [28] conducted long-term load tests and fatigue load tests on ordinary concrete beams and sea-sand concrete beams and accelerated the steel bar corrosion by soaking the tested beams in a chloride salt solution. It was found that the corrosion caused by the sea sand had no effect on the long-term deflection of the test beams but reduced the fatigue life greatly. Liu et al. [29] obtained the deterioration law of the flexural capacity of reinforced concrete beam damaged by different peak fatigue loads. The different fatigue loading conditions were applied on the specimens 200 000 times and then the specimens were eroded with seawater for 100 days, and apply static load until it is destroyed to study the initial stiffness, ultimate load, and yield load. Wu et al. [30] discussed effects of prefatigue damage on high-cycle fatigue behavior and chloride permeability of RC beams. The experiment processes included initial fatigue loading followed by 3 months of NaCl solution wet-dry cycles without loading, and then, fatigue life tests were carried to investigate the high-cycle fatigue behaviors of crack widths, deflections, and fatigue life and chloride permeability of RC beams. Liu et al. [31] studied the electrochemical characteristics, corrosion fatigue behavior, and failure mechanism according to the electrochemical measurement, fracture morphology, and wire life. His results evidence the synchronization of corrosion and fatigue and show the accelerated corrosion due to static and fatigue stresses. Guo et al. [32] studied that the fretting-fatigue failure evolved from surface microcracks at the trailing edges generated from a mixed slip regime. Stroński et al. [33] studied the influence of reinforcement type on the flexural behavior of reinforced concrete beams. Bagheri et al. [34] used an effective numerical method to study the time-varying reliability of reinforced concrete beams corroded by chloride ion considering cognitive uncertainty. Charalambidi et al. [35] investigated the critical parameters that affect fatigue performance of reinforced concrete (RC) beam. Triantafyllou et al. [36] reviewed thoroughly available experiments and analytical approaches in the relevant international literature and introduced a calculation model for assessing steel bar mass loss. They also studied that effect of patch repair and strengthening with EBR and NSM CFRP laminates for RC beams with low, medium, and heavy corrosion [37] and that corroded RC beams' patch repaired and strengthened in flexure with fiber-reinforced polymer laminates [38]. Charalambidi et al. [35] investigated two different amplitudes of cycles and discussed the different fatigue life and modes of failures.

In this paper, the experiment was divided into two stages. Firstly, the sustained load tests of RC beams were carried out in different exposure conditions about one year. Secondly, the RC beams suffered from different damages which were subjected alternating action of fatigue and corrosion environment and the tested beams were eroded by immersion in a NaCl solution wet-dry cycles. The beam deflection, the fatigue damage cumulative development, and the microscopic characteristics of the steel bar fractures were investigated, providing reference for the future study of damaged concrete beam durability.

2. Experimental Program

Design drawing of the dimensions of reinforced concrete beam used in the test is shown in Figure 1. The beams were reinforced with two 12-mm deformed bars of HRB335 in tension, in which the steel yield stress was 335 MPa and ultimate stress was 510 MPa, respectively, under direct tension. The shear steel bars comprised 10 mm bars of HPB235, spaced at 100 mm intervals in the shear span. The top-layer steel bars with two 10 mm bars of HPB235 were used in the shear span. The cover of the steel bars was 25 mm in thickness. The lengths of the moment span and two shear spans are 500 mm and 700 mm, respectively. The 28-day compressive strength and elastic modulus of the concrete are 51 MPa and 36663 MPa, respectively. Two of the beams, which are Beam 3 and Beam 4, were mixed with chloride salt (3% of cement mass) during casting.

The testing was conducted in two stages, and the list of specimens is shown in Table 1. The first stage included coupling of the sustained load and environment test. Specimens C-1 was monotonically loaded to failure under

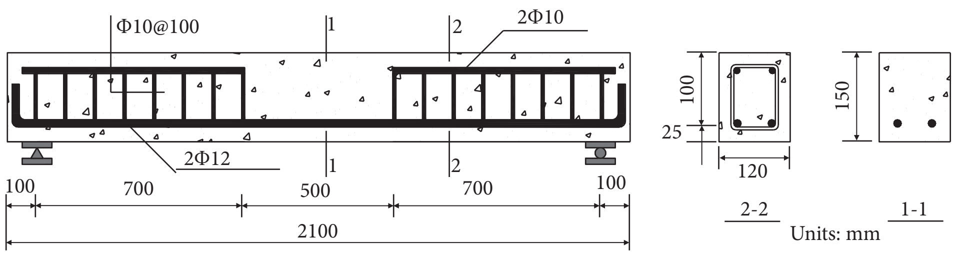


Figure 1: Design drawing of the dimensions of reinforced concrete beam.

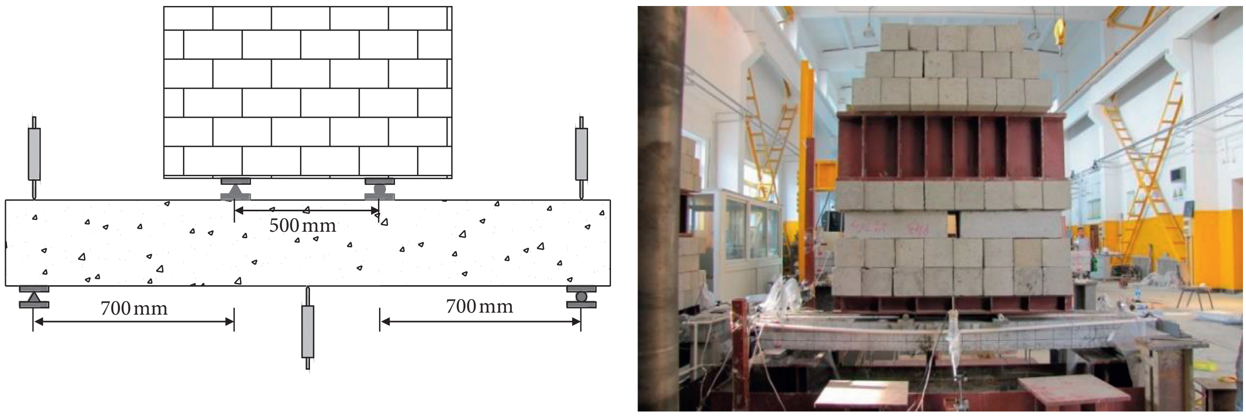
Table 1: The test results of six beams.

Beam no.	First stage		Second stage			Notes
	Environment	Load	Environment	Fatigue load	Loading process	
C-1	Tested up to failure	—	—	—		
1	Air environment	0 kN	—	—	Apply static load until destroyed	A few holes and no cracks
2	Drying-wetting environment	0 kN	Air environment	2.1 kN–21 kN	Apply fatigue load until destroyed	A few holes and no cracks
3	Drying-wetting environment	9 kN	Air environment	2.1 kN–21 kN	Apply fatigue load until destroyed	Mixed with NaCl, a few holes, and crack width $\omega_{max} \leq 0.15$ mm
4	Drying-wetting environment	9 kN	Corrosion environment	2.1 kN–21 kN	Corrosion 45 d ⟶ fatigue 4 w times ⟶ corrosion 45 d ⟶ apply fatigue load until destroyed	Mixed with NaCl, a few holes, and crack width $\omega_{max} \leq 0.15$ mm
5	Drying-wetting environment	9 kN	Corrosion environment	2.1 kN–21 kN	Corrosion 45 d ⟶ fatigue 4 w times ⟶ corrosion 45 d ⟶ apply fatigue load until destroyed	Crack width $\omega_{max} \leq 0.15$ mm
6	Drying-wetting environment	9 kN	Corrosion environment	2.1 kN–21 kN	Corrosion 45 d ⟶ fatigue 6 w times ⟶ corrosion 45 d ⟶ apply fatigue load until destroyed	A few holes and crack width $\omega_{max} \leq 0.15$ mm

four-point bending to obtain yield load and ultimate of the beam, which were Py = 28 kN and Pu = 30 kN. Beams 1 and 2 are reference beams for different environments. Beams 3–6 are sustained load beams, and 30% of the ultimate bearing capacity (Pu) of these beams was applied by weight. The schematic of the sustained loading test setup is shown in Figure 2. The midspan deflection of each beam was measured using linear voltage displacement transducers (LVDTs) every day. The testing environments are an air environment and a drying-wetting environment. The drying-wetting environment was achieved by using a circular sprinkler, and the loading time was 331 days. Figure 3 shows the variable temperature and humidity data that were recorded regularly over the 331 day period.

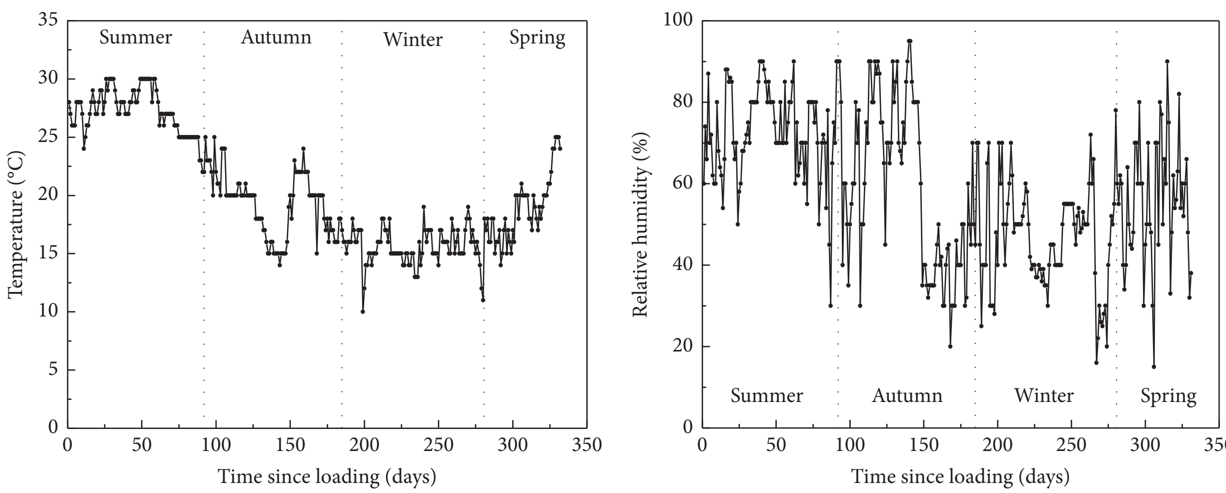
The second stage was the corrosion and fatigue testing. After the first phase, the beams were removed, and the appearance and cracks were evaluated. Detecting of the appearance and cracks are shown in Figure 4. The test results of six beams are listed in Table 1. In the second stage, Beam 1 was damaged by a static load. Beams 2 and 3 were directly damaged by a fatigue load. Beams 4–6 were tested by corrosion ⟶ fatigue load ⟶ corrosion ⟶ fatigue load until destruction. The prefatigue damage number of times of Beam 5 and Beam 6 are 40,000 and 60,000, respectively. The corrosion test was achieved by alternating cycles of wetting-drying in a corrosion tank: a cycle was defined as wetting for 2 days and drying for 1 day. Schematic of the corrosion test setup is shown in Figure 5. The corrosion medium was a NaCl solution of 5% mass fraction. The fatigue load was controlled by a hydraulic servo system in a four-point bending load configuration. Schematic of the fatigue loading test setup is shown in Figure 6. The upper limit of the fatigue load was 21 kN (70% of Pu) and the lower limit was 2.1 kN (7% of Pu); the stress ratio is 0.1, with a loading frequency of 2 Hz. The deflection and crack width were recorded during the test. The failure of the beams was marked by the fracture of the steel bars.

Li et al. studied the fatigue behavior of naturally corroded plain reinforcing bars. Segments of corroded plain reinforcing bars were firstly extracted from an aged reinforced concrete (RC) pole after its breaking, and then, the fatigue fracture mechanism of the corroded specimens was interpreted by using scanning electron microscope (SEM) images [39]. In this study, the steel bars were removed and the fracture surfaces were scanned with an electron microscope after failure occurred [40]. In addition, after the test, tensile reinforcement in the pure bending section was taken out to measure the steel corrosion rate.



(a) (b)

Figure 2: Schematic of the sustained loading test setup. (a) Sketch of loading test equipment. (b) Loading test equipment.



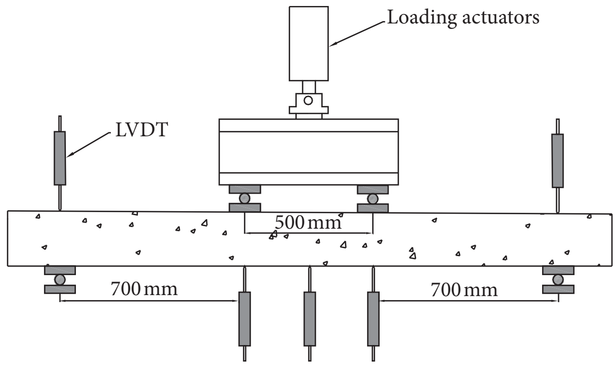
(a) (b)

Figure 3: Temperature and humidity variations. (a) Temperature. (b) Relative humidity.

(a) (b)

Figure 4: Detecting of the appearance and cracks. (a) Appearance and cracks of beam. (b) Cracks.

Figure 5: Schematic of the corrosion test setup.



(a)

(b)

Figure 6: Schematic of the fatigue loading test setup. (a) Sketch of loading test equipment. (b) Loading test equipment.

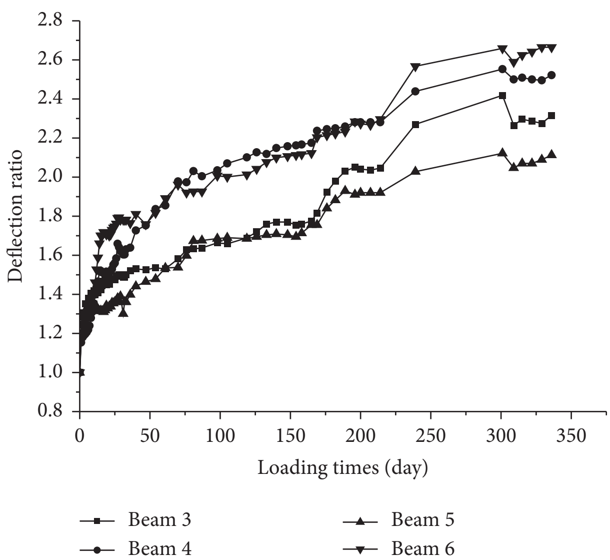


Figure 7: Curves of beam deflection under sustained load.

3. Result and Analysis

3.1. Deflection of Beams under the Coupled Sustained Load and Environment. The deflection ratio is the ratio of deflection to the initial deflection. Figure 7 shows the curves of the deflection ratio with testing time for each beam under the sustained load. In the first stage, during the first 25 days after loading, the deflection of the tested beams increased approximately linearly and increased approximately from 35% to 45% of the total deflection. During the second stage, exceeding 25 days after loading, the deflection tended to increase more slowly and became relatively stable. After 225 days, the deflection tended to lessen. However, the deflection growth rates of the chloride-mixed Beams 3 and 4 and that of the nonchloride-mixed Beam 5 are almost the same, indicating that chlorides have no apparent effect on the deflection of a beam under a sustained load, which is in agreement with [11]. After 350 days of the sustained load test, unloading was performed and the appearance of the tested beams was checked. Except for a few holes, there were no appearance defects that affected the mechanical performance. The cracks of Beams 3–6 were within the limits, and no steel corrosion cracks was observed.

3.2. Influence of Corrosion and Fatigue on the Fatigue Life. A static load was applied to Beam 1 until failure, resulting in three phases of concrete cracking, steel bar yielding, and concrete crushing. The failure of Beam 1 includes the typical modes of flexural failure. A fatigue load was applied to Beams 2–6. During the loading process, cracks opened and closed as the fatigue load changed. The residual deflection also increased with the number of fatigue load cycles. When a beam was close to failure, the reinforcing steel bar broke suddenly at one of the loading points, crushing the concrete in the compression zone. The fatigue damage development processes and the forms of fatigue life of all beams were basically consistent. Figure 8 shows the fatigue failure form of the tested beams. The fatigue life and number of steel bars broken for each beam are shown in Table 2.

Influence of alternating action of corrosion and fatigue: for the nonchloride-mixed Beams 2, 5, and 6, the fatigue life of Beams 5 and 6 under the alternating action of corrosion and fatigue reduced by 56% and 60%, respectively, compared with the fatigue life of Beam 2 under the atmospheric environment. For chloride-mixed Beams 3 and 4, the fatigue life of Beam 4 under the alternating action of corrosion and fatigue was significantly lower than that of Beam 3 under the atmospheric environment, indicating that the alternating action of corrosion and fatigue greatly reduced the fatigue life of the beam. Other researchers have observed the same phenomenon.

Influence of corrosion damage: the steel bars of the chloride-mixed Beams 3 and 4, which experienced the first stage test, were corroded to a certain degree. The fatigue lives of Beams 3 and 4 decreased significantly compared with that of Beam 2. Therefore, steel corrosion has a serious effect on the fatigue life of concrete beams. Compared with Beam 3, the fatigue life of Beam 4 was reduced by 68%, indicating that the corrosion due to external environment will accelerate the corrosion of steel, leading to a further decrease in fatigue life.

Influence of fatigue damage: the difference between Beam 5 and Beam 6 is the prefatigue damage. The fatigue

(a)

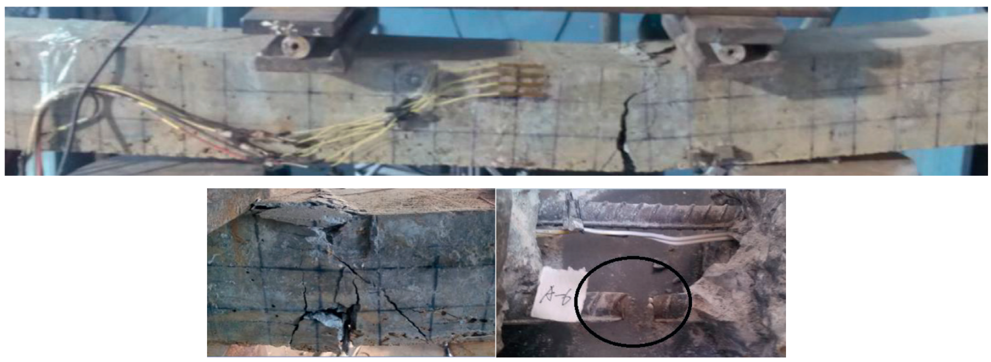
(b)

(c)

(d)

Figure 8: Continued.

(e)



(f)

Figure 8: Fatigue failure form of the tested beams. (a) Beam 1. (b) Beam 2. (c) Beam 3. (d) Beam 4. (e) Beam 5. (f) Beam 6.

Table 2: Fatigue life of each tested beams.

Beam no.	2	3	4	5	6
Fatigue life	326258	217600	70229	142311	130162
Steel bars broken	1 steel bar broken	1 steel bar broken	1 steel bar broken	1 steel bar broken	1 steel bar broken

damage of Beam 6 is greater than that of Beam 5, and the fatigue life of Beam 6 is relatively reduced compared to that of Beam 5. However, the fatigue lives of Beam 5 and Beam 6 are not considerably different, decreasing by 56% and 60%, respectively, showing that the extent of prefatigue damage within a certain range has no significant effect on the ultimate fatigue life of the beam.

Influence of steel corrosion rate: after fatigue loading test, the tensile steel bars were removed and two tension-reinforcing steel bars of each beam were labelled as A and B. The steel bars of the moment span were cut into parts, and the corrosion rates were measured. The average mass loss ratio of corroded bars was list in Table 3. It can be seen from Table 3 that the steel bar is rusted only by chloride salt soaking corrosion rather than accelerated corrosion by electricity; when the soaking time is shorter, the corrosion rate of the steel bar is generally lower, but the fatigue life of the beam is reduced more. As a result, the uneven steel corrosion caused by chlorine salt soaking is more harmful.

3.3. Influence of Corrosion and Fatigue on the Load-Deflection Curve. The load-deflection curve of each tested beam is shown in Figure 9. As the fatigue load changes, the deflection also changes cyclically. With the increase in the cycles of fatigue loading, the maximum deflection and residual deflection increased gradually, and the damage of the beam clearly accumulated. The maximum deflections of Beams 2–6 after the initial static load were 14.01 mm, 12.52 mm, 11.99 mm, 12.95 mm, and 11.30 mm, respectively. When the tested beams were damaged, the maximum deflection reached 15.80 mm, 15.44 mm, 15.60 mm, 19.85 mm, and 17.17 mm and increased by 1.79 mm, 2.92 mm, 3.07 mm, 6.90 mm, and 5.79 mm, respectively.

Here, the deflection corresponding to the lower limit is taken as the residual deflection, and the deflection corresponding to the upper limit is taken as the maximum deflection. Figure 10 shows the deflection-fatigue load cycle curve of each tested beam. The deflection development curves of each beam are similar and include an inflection point. The deflection of each beam increased rapidly after several initial fatigue load cycles, slowed, and then remained basically constant. After the inflection point was reached, the deflection increased faster until failure. The number of cycles and corresponding deflection at the stage of initiation of significant deflection increase are shown in Table 4.

Table 3: Steel corrosion rates.

Beam no.	2		3		4		5		6	
	A	B	A	B	A	B	A	B	A	B
Steel corrosion rate (%)	0.4	0.3	0.8	0.51	0.39	0.47	0.6	0.49	0.55	0.54

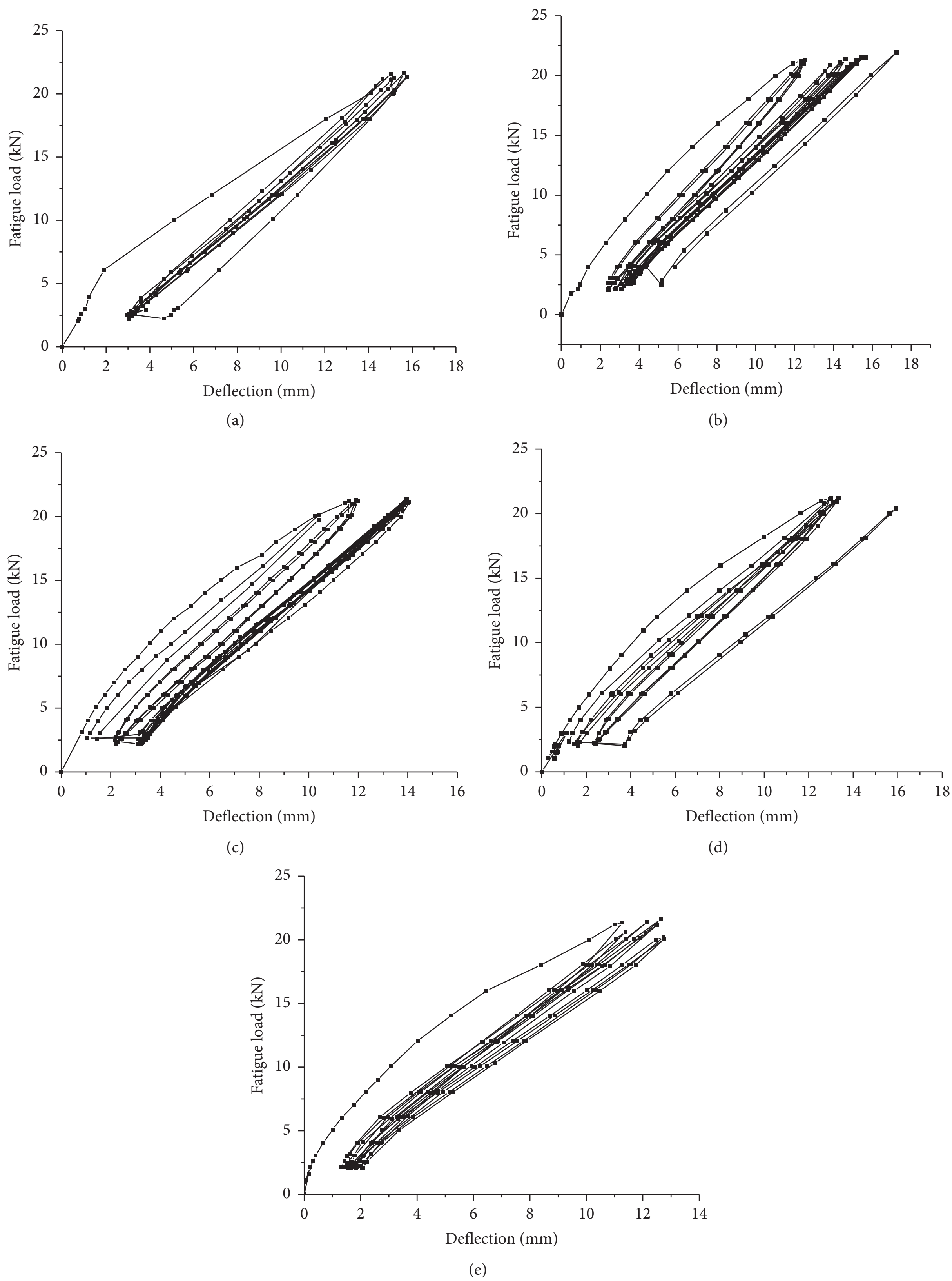


Figure 9: Load-deflection curve of each beam. (a) Beam 2. (b) Beam 3. (c) Beam 4. (d) Beam 5. (e) Beam 6.

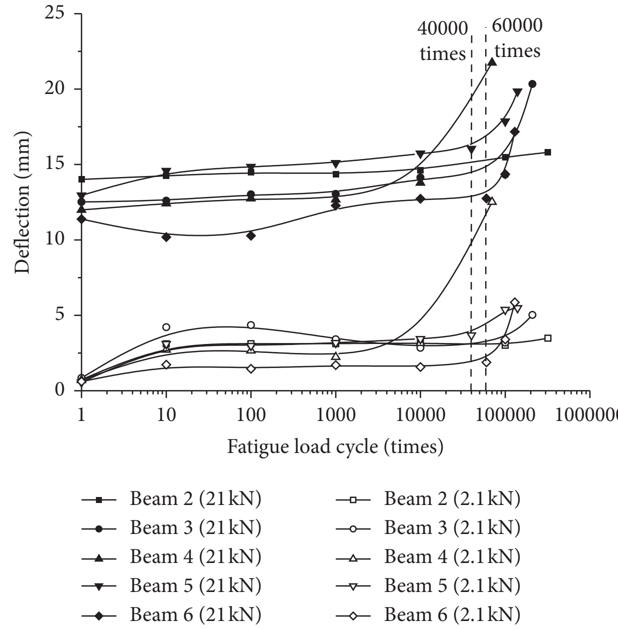


Figure 10: Deflection-fatigue load cycle curve of each tested beam.

The inflection points of Beams 5 and 6 under the alternation of corrosion and fatigue appears at an earlier position than that of Beam 2 under the air environment, meaning that the process of slow deflection development is shortened; therefore, the alternating action of corrosion and fatigue promotes the corrosion of steel bars, resulting in the shortening of the crack growth process and the premature fracturing of the steel bars. The fatigue life of the beam also decreased. The maximum deflections of Beams 5 and 6 are similar, which shows that the prefatigue damage in a certain range has no clear effect on the deflection of beams.

The inflection point of chloride-mixed Beam 3 appears at an earlier position than that of Beam 2, and the process of slow deflection development is shortened, indicating that chlorides in concrete will cause corrosion of the steel bars, thereby reducing the performance of the beam. Compared with Beam 3, Beam 4 has a slower development of deflection and the deflection increases more rapidly near the point of fatigue failure. Therefore, the corrosion in an external environment will further promote the corrosion of the steel bar in a chloride-mixed concrete beam, leading to a faster accumulation of damage.

3.4. Influence of Corrosion and Fatigue on the Cracks. The crack width corresponding to the fatigue load lower limit is taken as the residual crack width, and the upper limit is taken as the maximum crack width. The crack width-fatigue load cycle curve of each tested beam is shown in Figure 11. During the initial fatigue of 10,000 cycles, the crack width of each beam increased slowly and then remained basically stable under the lower limit. Then, the crack growth accelerated until failure. There is an inflection point in the curve. During the initial 1000 cycles of fatigue loading, the crack width of each beam was basically constant under the upper limit, and then, the crack grew rapidly until failure. Before fatigue failure, the maximum crack width of all the tested beams was only 0.35 mm, and the residual crack was only 0.09 mm, and no apparent widening of the cracks occurred, indicating that no clear precursor was expressed before damage, and the fatigue failure was a sudden brittle failure. The development of the maximum crack width and the corresponding fatigue times were listed in Table 5.

3.5. SEM Observation of Fracture Sections. After the corrosion fatigue test, the steel bars were removed and cleaned. Then, microscopic scanning was performed on the fractures with an electron microscope. The results of Beams 2, 3, and 5 are shown in Figure 12–14.

The steel fracture source zone of Beam 2 is located at the start of the radial stripe, as shown in Figure 12(a). The development zone, as shown in Figure 12(b), presents a typical fingerprint-like pattern of metal fatigue development. After the fatigue crack developed steadily for a period, the rate of development gradually accelerated, and the transition zone was formed, as shown in Figure 12(c). When the crack development reached the fracture zone, fatigue fracturing occurred. Figure 12(d) shows the fracture zone with evident dimples.

As shown in Figure 13(a), some rusty materials are observed at the edge of the source zone of Beam 3; these materials may be the corrosion products of the chlorides on the surface of the steel bar. Figure 13(b) shows the crack development zone with evident fatigue development with stripe and crystal-like characteristics due to the chlorides corrosion. Figure 13(c) shows the fracture zone with evident dimples.

Table 4: The number of cycles and correspo*Beam 3*nding deflection at the stage of initiation of significant deflection increase.

	Beam 2				Beam 3				Beam 4				Beam 5				Beam 6			
Number of cycles	3	10,000	1,50,000	3,00,000	3	10,000	1,80,000	2,10,000	3	10,000	50,000	70,000	3	10,000	80,000	1,40,000	3	10,000	80,000	1,30,000
Deflection (mm)	14.01	14.63	15.63	19.8	12.52	14.33	15.28	20.34	11.99	13.79	14.66	21.75	12.95	15.73	17.74	19.85	11.38	12.73	14.27	17.17
Rate of increase	0	4.4%	11.60%	27%	0	12.90%	22%	62.50%	0	15%	22.30%	79.70%	0	21.50%	37%	53%	0	12%	25%	51%

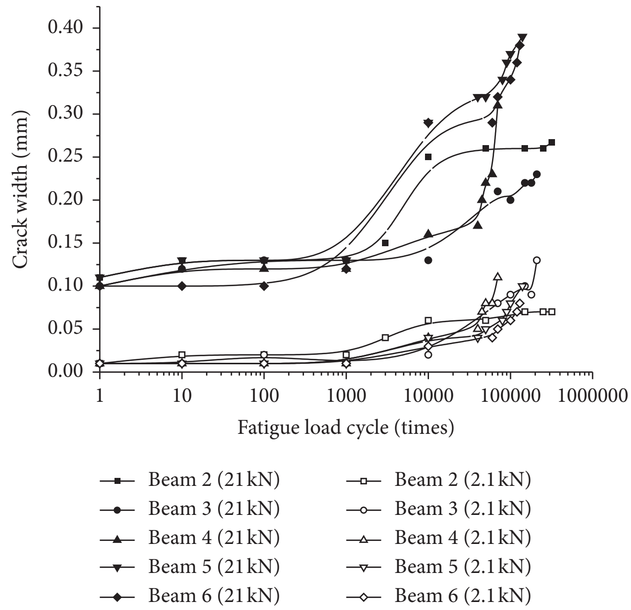
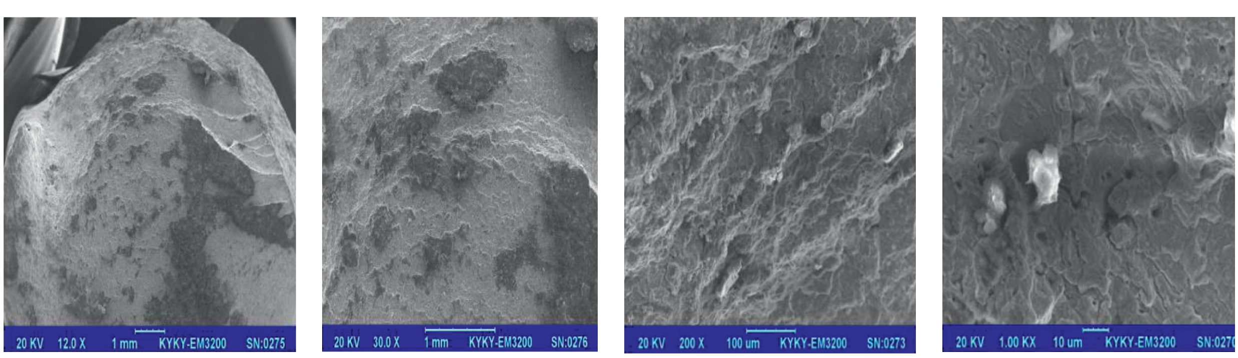


Figure 11: Crack width-fatigue cycle curve of each tested beam.

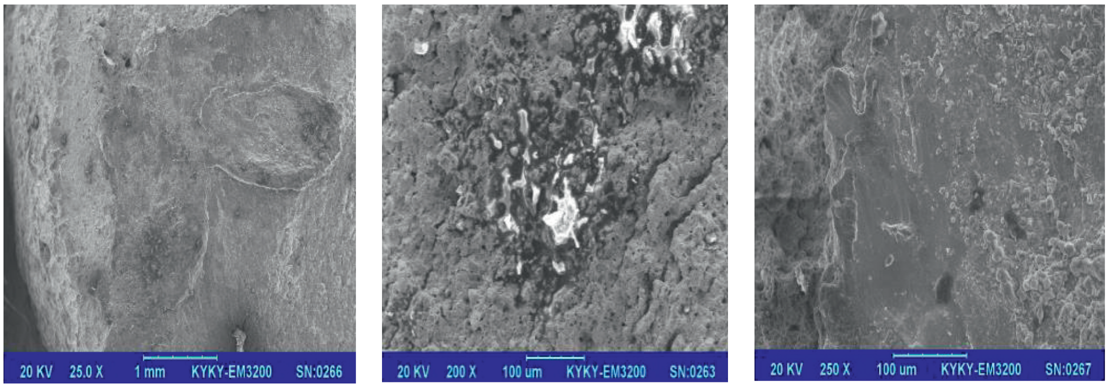
Table 5: The number of cycles and corresponding crack width.

Beam 2		Beam 3		Beam 4		Beam 5		Beam 6	
Number of cycles	Crack width (mm)	Number of cycles	Crack width (mm)	Number of cycles	Crack width (mm)	Number of cycles	Crack width (mm)	Number of cycles	Crack width (mm)
3	0.15	3	0.11	3	0.16	3	0.28	3	0.28
10,000	0.25	10,000	0.2	10,000	0.16	10,000	0.29	10,000	0.29
1,50,000	0.26	1,80,000	0.22	50,000	0.22	80,000	0.34	80,000	0.34
3,00,000	0.276	2,10,000	0.23	70,000	0.31	1,40,000	0.39	1,30,000	0.38



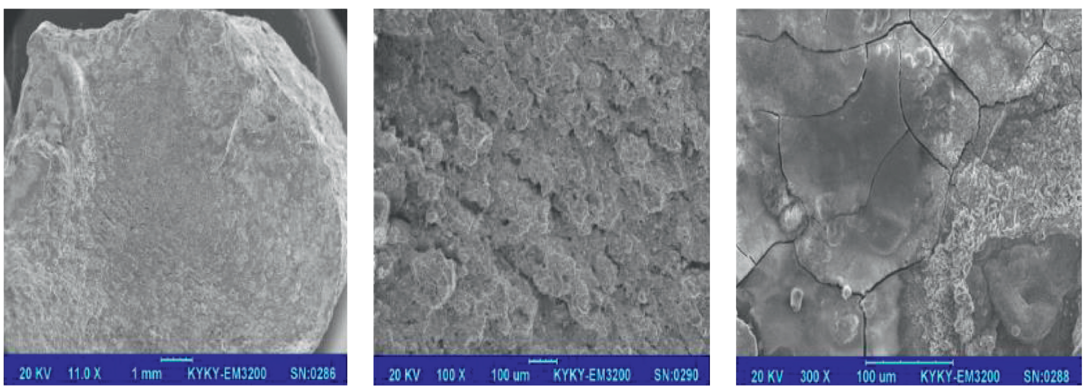
(a) (b) (c) (d)

Figure 12: Steel fatigue failure surfaces of Beam 2. (a) Source zone. (b) Development zone. (c) Transition zone. (d) Fracture zone.



(a) (b) (c)

Figure 13: Steel fatigue failure surfaces of Beam 3. (a) Source zone. (b) Development zone. (c) Fracture zone.



(a) (b) (c)

Figure 14: Steel fatigue failure surfaces of Beam 5. (a) Source zone. (b) Development zone. (c) Fracture zone.

Figure 14(a) shows the steel fracture source zone of Beam 5. The alternating action of corrosion and fatigue caused corrosion on the surface of the steel bar, and the edge of the whole section was sharp. The development zone presents crystal features around the fracture, as shown in Figure 14(b). As shown in Figure 14(c), the fracture zone shows a clear fracture surface with crystalline substance due to the erosion of the corrosive medium.

4. Conclusions

The main conclusions are the following:

(a) The deflection of RC beams continuously increased under the condition of a sustained load and wetting-drying cycles. However, the effect of chlorides on the deflection was not apparent. The cracks that formed during the static loading process in the reference beams and chloride-mixed beams were basically the same, and corrosion cracking of the steel bars did not occur in the chloride-mixed beams.

(b) Compared with the reference beam in the air environment, the fatigue life of the beams in the corrosion and fatigue environments were reduced by 56% and 60%, respectively, and that of the chloride-mixed beam was reduced by 78%. The fatigue life of chloride-mixed beams decreased by 33% compared with that of the reference beam in the air environment, and the fatigue life of the beam under the alternative action of corrosion and fatigue had a further decrease in fatigue life, showing that the chlorides in concrete will accelerate the steel corrosion and shorten the fatigue life. Fatigue life is less affected by the prefatigue damage under the alternation of corrosion and fatigue processes.

(c) After a certain number of initial fatigue load cycles, the deflection of each beam increased slowly, remained basically constant, and then increased rapidly when approaching failure, until the beam was destroyed. The crack accumulation in the chloride-mixed beam was faster than that in the reference beam during the fatigue process. The crack damage accumulation in the chloride-mixed salt beam under the alternation of corrosion and fatigue was faster than that of the beams under the air environment, indicating that the alternation of corrosion and fatigue accelerated the increase in the crack width in the chloride-mixed beam. The crack width tended to be stable under the fatigue load and developed slowly. Near failure, the crack width increased rapidly until the beam was destroyed.

(d) Due to the erosion of chlorides, there are some angular materials on the fracture surface of the chloride-mixed beam steel bars. Under the alternating action of corrosion and fatigue, the fracture surfaces of the steel bars were further eroded by chlorides with more angular materials. There were crystalline materials on the fracture surfaces, including chloride crystals, indicating that the chlorides sufficiently intruded into the interior of the steel bars and greatly affected the fatigue properties of the beams.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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