

Corrosion Behaviors of Carbon Steels in Artificially Simulated and Accelerated Marine Environment

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A novel marine corrosion simulation and acceleration test device was developed to study the corrosion performances in various marine zones. The corrosion behaviors of Q235 carbon steel was studied indoor using this device for comparing with the results of outdoor exposure test. The simulation and acceleration test results showed the corrosion rate of Q235 carbon steel after corrosion testing in various simulated marine zones for 10 days are: $v_{\text{immersion zone}}=0.21\text{mm/a}$, $v_{\text{tidal zone}}=0.24\text{mm/a}$, $v_{\text{splash zone}}=0.28\text{mm/a}$, $v_{\text{atmosphere zone}}=0.025\text{mm/a}$. The main corrosion products are $\alpha\text{-FeOOH}$, $\gamma\text{-FeOOH}$, Fe_3O_4 , $\text{Fe}(\text{OH})_3$, $\text{Fe}_8(\text{O},\text{OH})_{16}\text{C}_{11.3}$ and Fe_2O_3 . Among these marine zones, the samples in simulated splash zone showed the highest corrosion rate evaluated by weight loss and polarization curves and the smallest charge-transfer resistance according the EIS measurement. Obvious cracks and porous can be observed on rust layer of the samples in splash zone, indicating the corrosion products formed are instable. Compared with the corrosion behavior of Q235 carbon steel exposed outdoor in natural marine environment for 2 years, the corrosion tendency, corrosion production and electrochemical property of carbon steel in different simulated marine zones of this device are well consistent with that in actual marine corrosion tests. The device not only has excellent simulation of the major parameters and conditions in various marine zones, but also has a good acceleration performance.

Keywords: marine environment, simulated and accelerated tests, corrosion, electrochemistry, carbon steel

1. INTRODUCTION

The marine corrosive environments are usually divided into five zones, named atmospheric, splash, tidal, immersion, and sea mud zone. To evaluate corrosion performance accurately, researchers

often use outdoor field exposure test with the offshore long scale hanging specimens[1,2]. It is the most reliable method, however, it is also labor intensive and inconvenient for maintenance and specimen inspection. In addition, because of the severe marine environment, the specimen is easy to lose. Therefore, it can achieve a lot of scientific and reasonable test data in a short period of time and has great significance for the development of marine corrosion-resistant materials through the development of indoor marine corrosion simulation and acceleration test device to simulate real marine environment corrosion process.

To solve these problems, many simulation and acceleration test studies had been conducted in laboratory-controlled environment[3,4,5]. Nishikata, et al.[6], used an experimental cell for monitoring the corrosion rate of steels and carried out simulation test in a cyclic wet-dry apparatus. Dong, et al.[7], certified the characteristics of rusts formed on carbon steel under alternate dry/wet conditions in laboratory and discovered the law of rusts change in marine atmospheric zone. Hou, et al.[8], designed a device to simulate the marine environment and elaborated the corrosion features of carbon steel in marine splash zone. Mu, et al.[9], investigated the corrosion behavior of Q235B carbon steel in simulated tidal zone. Smith, et al.[10], developed a model for the prediction rates associate with steel subjected to synthetic produced water. However, most of them can only simulate parts of marine zones and few studies was reported regarding the correlation between laboratory and field exposure tests.

In this study, an improved marine corrosion simulation and acceleration test device were designed and fabricated, which can simulate the natural marine environment and realize the functions of wetting-drying alternation, corrosive atmospheres control, different marine corrosion zone simulation and so on. In order to evaluate the reliability and acceleration performance of the device, the corrosion behaviors of Q235 carbon steel in different simulated marine zones were studied by SEM morphology observation, EDS, XRD and electrochemical measurements and the correlation with field exposure tests was discussed.

2. EXPERIMENTAL

2.1 Test device

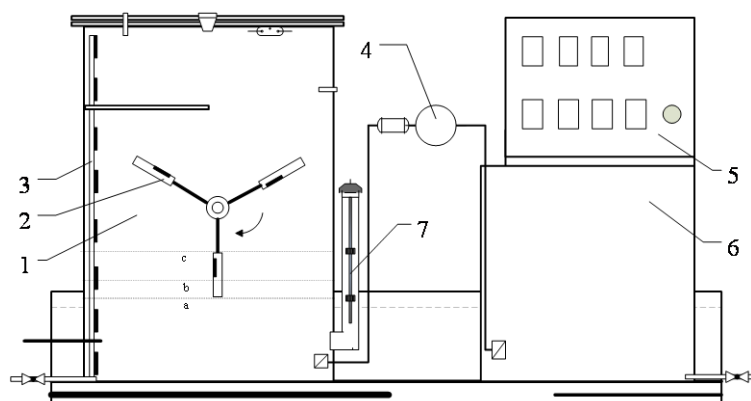


Figure 1. Schematic diagram of marine corrosion simulation and acceleration test device. (1) experimental tank; (2) rotating paddles; (3) sample holder; (4) peristaltic pump; (5) main control panel; (6) water storage tank; (7) float level meter

As shown in Fig 1, the main structure of the device was experimental tank (1), water storage tank (6), and main control panel (5). Two tanks were connected by peristaltic pump (4) and a float level meter (7) were mounted in the experimental tank for accurate control of the tidal range. Inside the experimental tank there were fixed sample holder (3) and rotating paddles which act as the components for wave surging and splashing (2).

The device is able to simulate different marine corrosive environments such as atmosphere, splash, tidal, and immersion zone. The experimental tank and the storage tank were filled with artificial seawater. Maximum water level was 255 mm and minimum was 100 mm. the rotating speed of blades was 45 rpm. At the maximum water level, the rotating blades began to work to simulate the waves splashing. While at the minimum, hot-air drier started to dry the specimen. As the blade rotating for 10 minutes, the water level began to fall, followed by the hot-air drier for 30 minutes, then the water level began to rise. The temperature of the artificial seawater was set as 35°C. The temperature of the hot-air drier was 35°C. The experimental duration was 10 days.

2.2 Materials and experimental tests

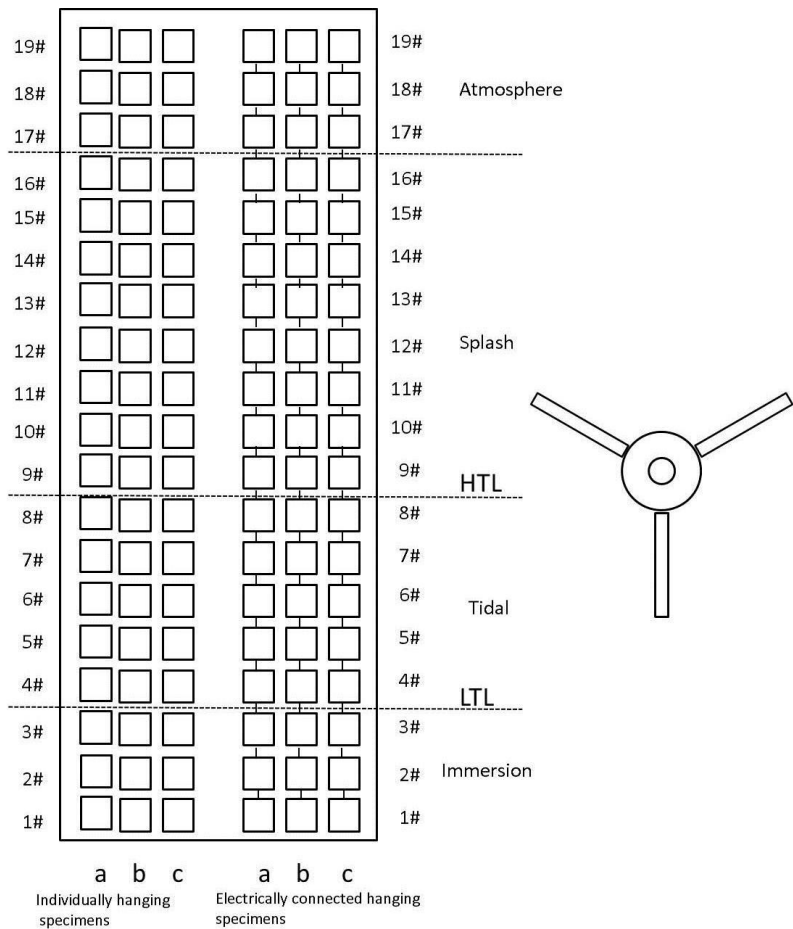


Figure 2. Schematic diagram of specimens loaded position in the marine corrosion simulation and acceleration test device. HTL: high tide line; LTL: low tide line

Q235 carbon steel was selected and the chemical compositions were listed in Table 1. The specimens were cut into pieces with a size of 50×25×4 mm for evaluating the average corrosion rate, and with a size of 10×10×3 mm for electrochemical testing. The electrochemical specimens were prepared with a fixed exposed surface area, and the rest were isolated from contact with the test solution by epoxy resin. The electrically connected hanging specimens were electrically connected with conductive wires and the connecting portion was sealed with silicone gel. The specimens from the bottom up were numbered from 1# to 19#, to be more specific, 1#~3# in immersion zone, 4#~8# in tidal zone, 9#~16# in splash zone and 17#~19# in atmospheric zone, shown in Fig 2. Prior to the corrosion test, all the specimens were polished on silicon carbide papers up to 800# grit, followed by washing ultrasonically with acetone and then with anhydrous ethanol. The samples were kept in a vacuum desiccator for at least 24h and then weighed using an electronic balance (the precision is 0.0001g).

The corrosive medium in this experiment is artificial seawater (GB/T 19746- 2005)[11] and its components were listed in Table 2. The specimens were taken out from the simulation and acceleration test device after 1d, 5d and 10d of exposure, respectively. 3 parallel samples were used for each test. Corrosion rate was calculated based on the average values.

Table 1. Chemical compositions of Q235carbon steel

Elements	C	Si	Mn	P	S	Fe
Content (ω_t %)	0.12~0.20	≤ 0.30	0.30~0.67	≤ 0.045	≤ 0.045	Balance

Table 2. Chemical compositions of artificial seawater

Components	Content(g/L)	Components	Content(g/L)
NaCl	24.534	NaHCO ₃	0.201
MgCl ₂ ·6H ₂ O	11.111	H ₃ BO ₃	0.027
Na ₂ SO ₄	4.094	SrCl ₂ ·6H ₂ O	0.042
CaCl ₂	1.159	NaF	0.003
KCl	0.695	Kbr	0.100

2.3 Corrosion products analysis

The morphologies of corrosion products were observed by using a Quanta 250 scanning electron microscope (SEM) equipped with Energy Dispersive Spectrometer (EDS). The working distance is 10 mm and accelerating voltage is 20 kV. The composition of the corrosion products formed on the specimens were scraped off by a plastic blade, and then analyzed by Rigaku-RB X-ray diffraction technique (XRD). A step-scanning X-ray diffraction with a Cu target was used for the XRD, with 40kW intensity and a 2θ range of 10°~100°.

2.4 Electrochemical measurements

Potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) were performed in solution of artificial seawater by using PARSTAT 2273 electrochemical workstation. The test system was a conventional three-electrode cell, where the reference electrode was a saturated calomel electrode (SCE) and the counter electrode was a platinum sheet. The metal sample was fixed in a polymethyl methacrylate container as work electrode, leaving a working area of 3.14cm^2 . The polarization measurements were carried out at a 0.333 mV/s scan rate in air saturated artificial seawater solution at $25 \pm 2\text{ }^\circ\text{C}$, and the scan range was $\pm 500\text{ mV}$ (SCE) relative to the open circuit potential. The EIS studies were performed in the frequency range between 100kHz and 10mHz with a 10mV amplitude signal at open circuit. The sample was fixed on the sample holder and the corrosion experiment was carried out for 1d, 5d, 10d respectively in the simulation and acceleration test device. After testing, the sample was taken out and then carried out EIS measurement.

3. RESULTS AND DISCUSSION

3.1 Corrosion behavior of specimens in natural marine environment

The surface appearances of Q235 carbon steel specimens exposed in natural marine environment of Qingdao for 2 years are shown in Fig 3. Products of carbon steel in immersion zone have more outer rust. In atmosphere zone, the products are compact. Morphologies of products in splash and tidal zone are similar, which local substrates are exposed to the air. The XRD patterns of rust formed on specimens in field-exposed test are shown in Fig. 4. It is obvious that the main products are $\alpha\text{-FeOOH}$, $\gamma\text{-FeOOH}$, Fe_3O_4 , $\text{Fe}(\text{OH})_3$, $\text{Fe}_8(\text{O},\text{OH})_{16}\text{Cl}_{1.3}$ and Fe_2O_3 . The corrosion rates of specimens in field-exposed test in this experiment are exhibited in Figure 5, with the order of $v_{\text{splash zone}} > v_{\text{tidal zone}} > v_{\text{immersion zone}} > v_{\text{atmosphere zone}}$.

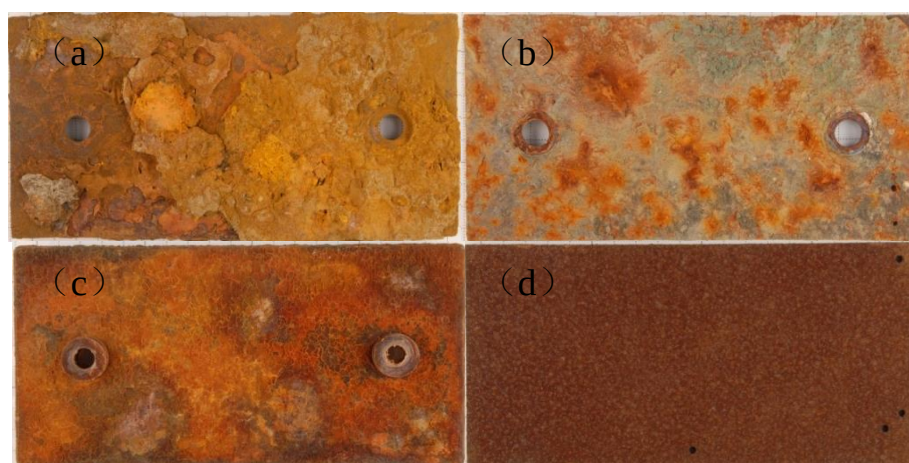


Figure 3. Appearances of specimens exposed in actual marine environment of Qingdao for 2 years (a) immersion zone; (b) tidal zone; (c) splash zone; (d) atmosphere zone

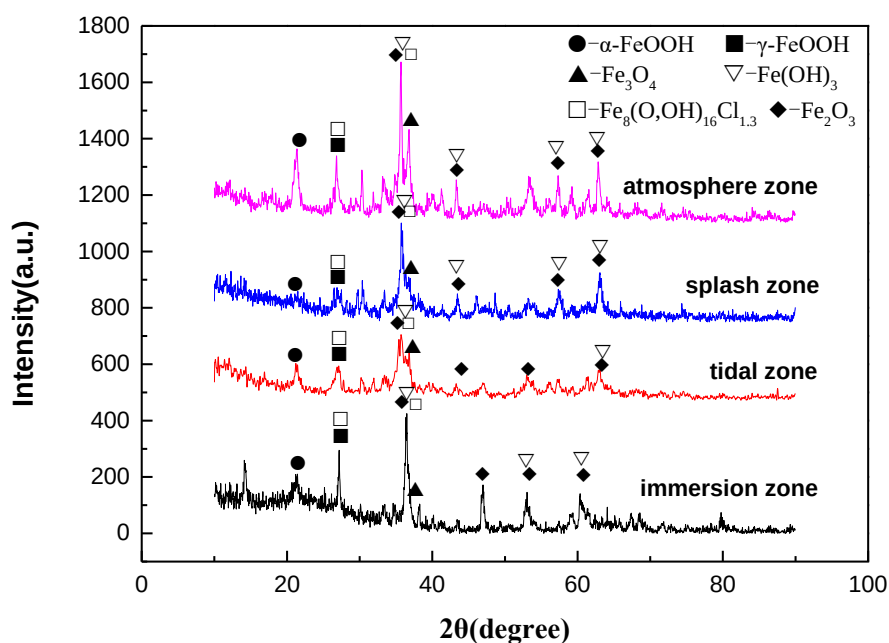


Figure 4. XRD patterns of rust formed on Q235 carbon steel exposed in actual marine environment of Qingdao for 2 years

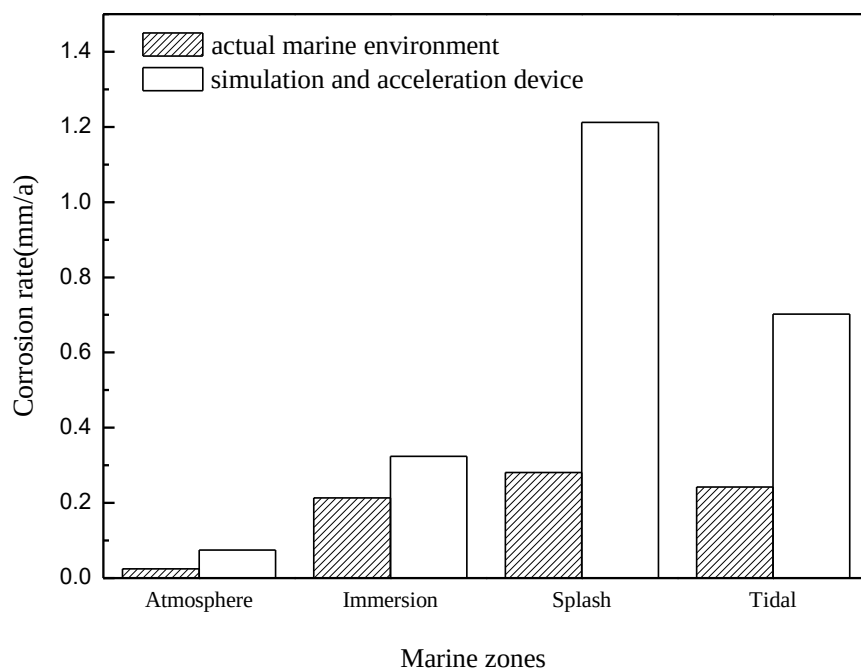


Figure 5. Corrosion rate of specimens in actual marine environment of Qingdao and in the simulation and acceleration device

The specific corrosion rates are $v_{\text{immersionzone}}=0.21\text{mm/a}$, $v_{\text{tidalzone}}=0.24\text{mm/a}$, $v_{\text{splashzone}}=0.28\text{mm/a}$, $v_{\text{atmospherezone}}=0.025\text{mm/a}$. Because of the exposure of local substrates in splash

and tidal zone, the exposed parts are anode and the others are cathode, forming the structure of small anode and large cathode. Therefore, the corrosion rates of carbon steel are higher than that in immersion and atmosphere zone.

3.2 Corrosion behavior of specimens in simulate marine environment

3.2.1 Weight loss analysis

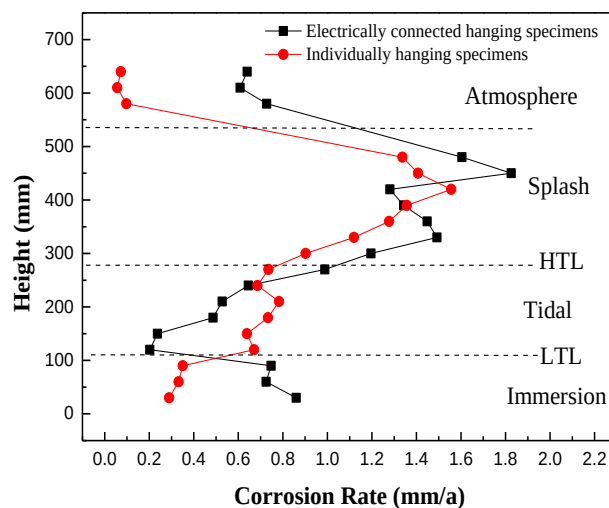


Figure 6. The corrosion rate curves of Q235 carbon steel exposed in the simulation and acceleration test device for 10 days

The corrosion rates of Q235 carbon steel exposed in atmosphere, splash, tidal, and immersion zones for individually hanging specimens and electrically connected hanging specimens are shown in Fig.6. The corrosion rates of Q235 carbon steel specimens by individually hanging in descending order are splash zone, tidal zone, immersion zone and atmospheric zone, which are consistent with the results of natural marine environment and previous literature[12,13]. In marine splash zone, the highest frequency of dry-wet alternate, plenty of oxygen and wave strikes make it the most serious zone with corrosion issue. Marine tidal zone also suffer dry-wet alternate and the oxygen is sufficient, which make it corrode more severe than immersion zone. The corrosion rate of Q235 carbon steel in atmospheric zone is minimal due to no directly exposed to seawater.

It is evident that the corrosion of individually hanging specimens located in tidal zone is more serious than that of electrically connected hanging specimens, which can be explained by that the different content of oxygen[14], leading to the formation of a macroscopical oxygen concentration cell between the specimens located in tidal and immersion zones. For the electrically connected hanging test, the specimens located in immersion zone are regarded as anode and the specimens in tidal zone are cathode and therefore be protected. This result shows that the corrosion behaviors for two kinds of hanging tests in the simulation and acceleration device are well consistent with the results of natural seawater exposure tests in Qingdao [15,16].

The average corrosion rates calculated of individually hanging specimens carried out in the simulation and acceleration test device are: $v_{\text{immersion zone}}=0.324\text{mm/a}$, $v_{\text{tidalzone}}=0.702\text{mm/a}$, $v_{\text{splash zone}}=1.212\text{mm/a}$, $v_{\text{atmospherezone}}=0.075\text{mm/a}$, respectively. Compared with the actual marine environment testing in Qingdao, the corrosion rates in all corrosive zones got in the simulation and acceleration device are larger as shown in Fig.5.

The common reason of the acceleration is that the temperature (35°C) is higher than the actual temperature of seawater. Higher temperature drives the reaction with a higher speed. For simulated immersion zone, the specimens are always in soaking conditions, therefore the temperature is the main influencing factor and the acceleration ratio is less than that in tidal and splash zones. However, the frequency of simulative tidal fluctuation and wave impact are much greater than the actual condition, making the acceleration ratio of corrosion in tidal, splash and atmosphere zones greater than that in immersion zone. Most of all, the wave striking intensity and tidal fluctuation frequency in splash zone could be greatly improved by controlling the rotating speed of blades in this simulation and acceleration device, therefore, the highest corrosion acceleration ratio 4.3 was obtained in simulation splash zone. Although a good correlation between the electrically connected hanging specimen in another kind of corrosion simulation device and offshore long scale hanging specimen in actual marine environment[17,18], the corrosion acceleration property of marine corrosion simulation device is important for fast corrosion assessment of marine materials and other relative corrosion research.

3.2.2 Corrosion morphologies

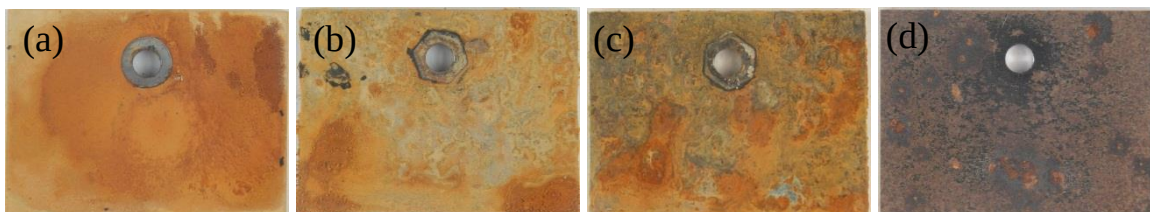
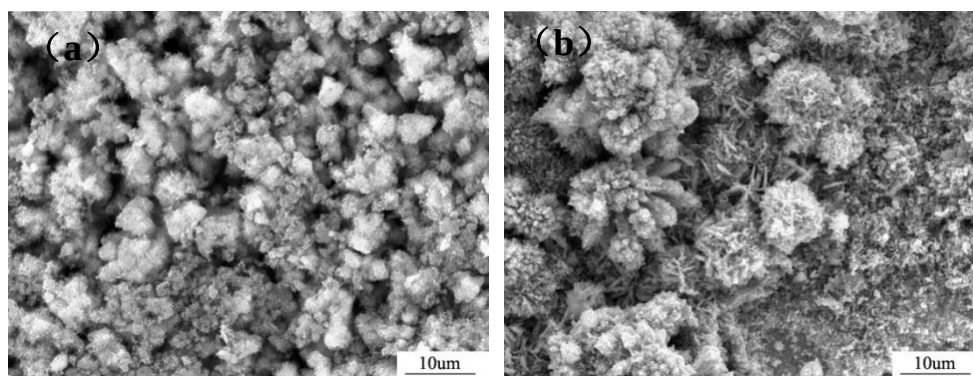


Figure 7. Macroscopic morphologies of Q235 carbon steel specimens by individually hanging for 10 days. (a)immersion zone; (b) tidal zone; (c)splash zone; (d)atmospheric zone



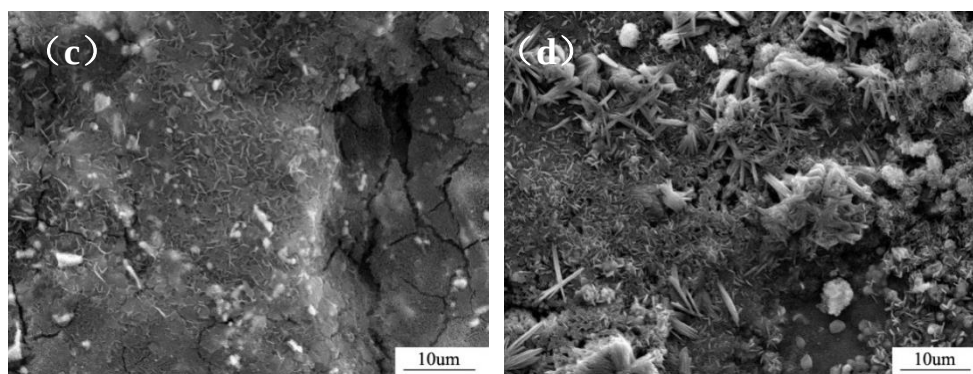


Figure 8. Microscopic morphologies of Q235 carbon steel specimens by individually hanging for 10 days. (a) immersion zone; (b) tidal zone; (c) splash zone; (d) atmospheric zone

The macroscopic appearances of specimens corroded in four corrosive zones are shown in Fig. 7. The results are consistent with that in natural marine environment. The rusts formed in immersion zone are divided into two layers. The outer rust layer is brownish yellow, very loose, covering the sample surface like mud and very easy to remove. The inner rust layer is black and combined adhered tightly with the metallic substrate. The rust formed in tidal zone is brownish yellow and the greyish white spots are calcium and magnesium salt. In wet cycle, calcium and magnesium ions deposit on the surface of the specimen and then concentrate in dry cycle. Concentration of the ions increases with time constantly, forming the visible white spots. The color of the rust layer appears darken from the outer part to the inner part in splash zone. Compared with the tidal zone and immersion zone, the content of black rusts increased significantly.

A series of SEM images of the specimens exposed in simulated various marine zones for 10 days is shown in Fig. 8. In immersion zone of Figure 8(a), the rust layer is compact and shows a granular distribution. Some flower-like crystalline phase can be observed on the surface of specimens in tidal zone, as shown in Figure 8 (b). The content of outer rust decreases obviously in marine splash and atmosphere zone. Since the wave impact and conversion of products[19], the content of outer rust of specimens in splash zone is the lowest as shown in Fig.8(c). Clubbed fine crystal products appear on the surface of specimens exposed to atmosphere as in Fig.8(d).

Both specimens in splash zone and tidal zone suffer dry-wet alternate and compare the weight-loss results and microscopic appearances, it is clear that the cracking and flaking off of rust caused by wave strikes is the main reason that makes corrosion of specimens in splash zone more serious.

3.2.3 XRD analysis of corrosion products

The XRD results show that the rusts formed on specimens are substantially almost the same in different corrosive zones, also the same close to the results in different corrosive zones in natural marine environment. It is mainly composed of α -FeOOH, γ -FeOOH, Fe_3O_4 , $\text{Fe}(\text{OH})_3$, $\text{Fe}_8(\text{O},\text{OH})_{16}\text{Cl}_{1.3}$ and Fe_2O_3 , just as reported in previous literatures[20,21]. Besides, it shows less content of α -FeOOH in splash zone and tidal zone. Compared with Fig. 4, it further shows the good

correlation between simulation and acceleration tests and field-exposed test. $\text{Fe}_8(\text{O},\text{OH})_{16}\text{Cl}_{1.3}$ is a kind of β -FeOOH and the formation of this unstable products is closely related to Cl^- [22].

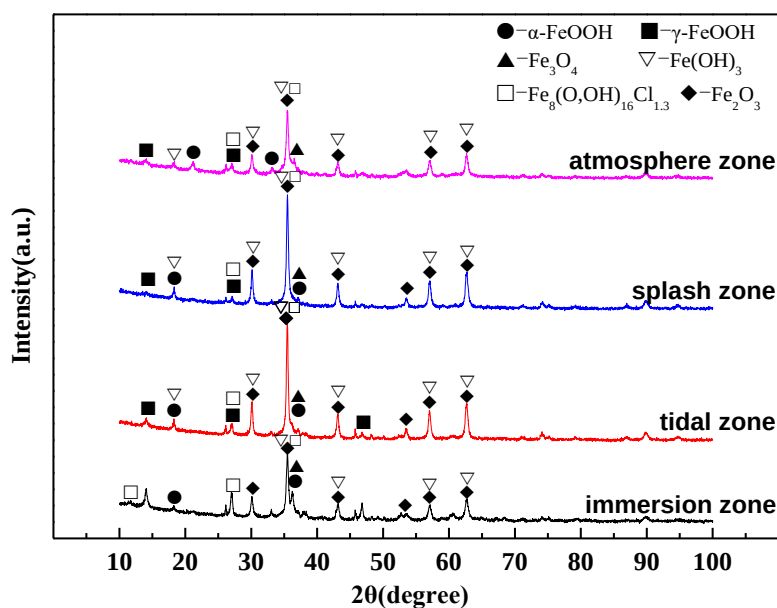


Figure 9. XRD patterns of rust formed on Q235 carbon steel specimens by individually hanging in various simulated marine zones for 10 days

The more unstable products of γ -FeOOH, $\text{Fe}(\text{OH})_3$ and $\text{Fe}_8(\text{O},\text{OH})_{16}\text{Cl}_{1.3}$ were found in tidal and splash zones, however such compounds could be gradually converted to stable structural substance α -FeOOH and Fe_3O_4 with the extension of time. The products contain less α -FeOOH and Fe_3O_4 in tidal and splash zones indicating that the corrosion is much more serious in these two zones. The results showed that the alternation of wet and dry promotes the formation of unstable products.

In atmosphere and immersion zone, more α -FeOOH can be detected. Combining the results with the analysis of corrosion rate and surface morphology, it can be concluded that α -FeOOH is compact and stable, which can effectively inhibit the corrosion.

3.2.4 Linear polarization measurements

Fig. 10 shows the polarization curves of Q235 steel samples in various simulated marine zones after exposure test in the simulation and acceleration test device for 1d, 5d and 10d, respectively. The reciprocal of linear polarization resistance is directly proportional to the corrosion current density, which is proportion to the corrosion rate, therefore, linear polarization measurement is widely applied to study the carbon steel corrosion[23].

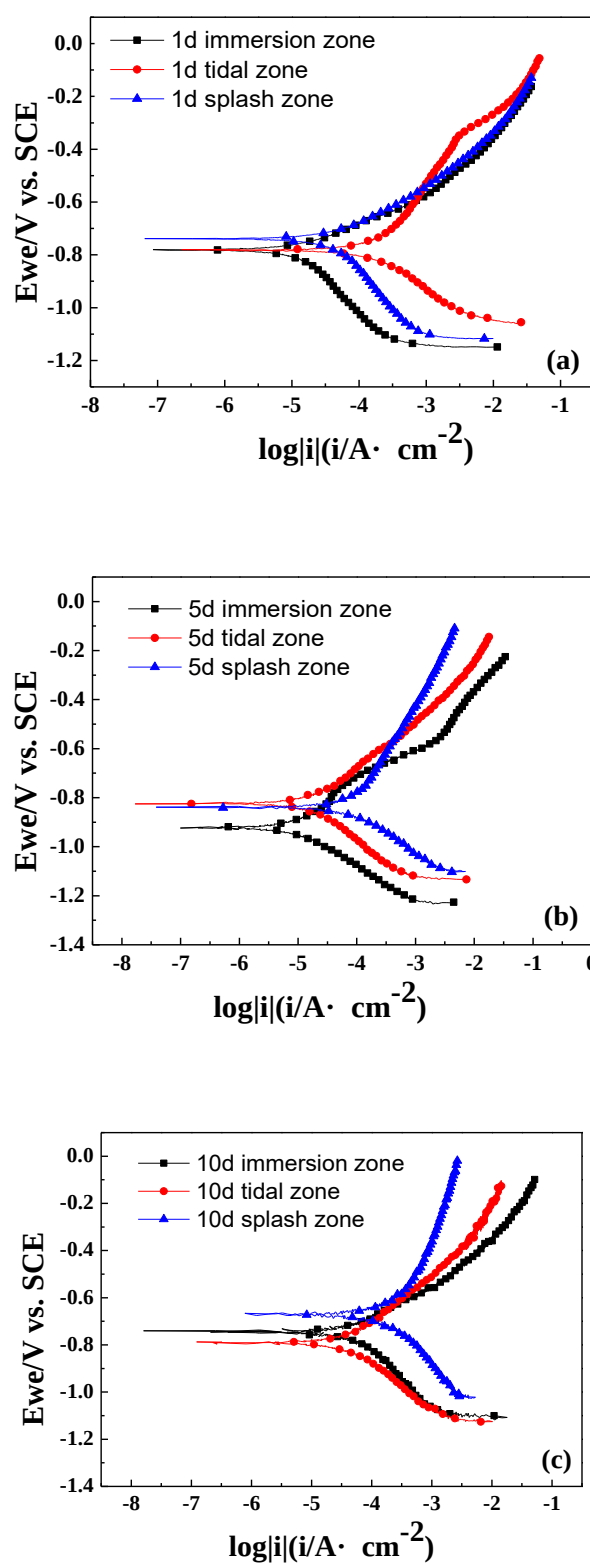


Figure 10. Polarization curves of Q235 steel samples in various simulated marine zones after different exposure periods in the simulation and acceleration test device. (a)1d; (b)5d; (c)10d.

According to the polarization curves in Fig.10 and the fitted results in Table 3, it can be found that the maximum corrosion current density of samples was obtained in tidal zone after the first day of testing, indicating the fast corrosion rate of samples in tidal zone in initial corrosion stage. This is attributed to the sufficient dissolved oxygen and the high frequency of wet-dry alternation in tidal zone, which will accelerate the corrosion process[24]. However, with the increase of corrosion cycles, the corrosion rate gradually decreased due to the thickening of the rust layer. On the other hand, the value of I_{corr} in splash zone is always much higher than that in other zones with the increase of cycles, indicating the corrosion rate cannot be depressed by rust formation in the long period testing in splash zone. This is due to the strong effect of splash impact and the high frequency of wet-dry alternation led to the removal of loose and porous rust layer, therefore the formation of protective corrosion products on the steel surface is difficult in this splash zone. The results of linear polarization are well consistent with the tendency of weight loss analysis in simulate marine environment.

Table 3. The fitted values of various electrochemical parameters evaluated from polarization curves shown in Fig. 10

Marine zones	Time	$E_{\text{corr}}(\text{mV})$	$I_{\text{corr}}(\mu\text{A}\cdot\text{cm}^{-2})$	$\beta_c(\text{mV/dec})$	$\beta_a(\text{mV/dec})$
Immersion		-780.8	13.3	278.7	112.6
Tidal	1d	-784.4	198.8	206.5	345.7
Splash		-738.2	47.7	340.2	147.8
Immersion		-923.2	12.4	168.2	263.2
Tidal	5d	-824.1	19.7	209.2	206.4
Splash		-838.8	94.1	187.6	429.5
Immersion		-744.8	58.8	274.1	155.7
Tidal	10d	-790.3	47.2	224.4	229.3
Splash		-671.8	290.8	373.2	567.8

3.2.5 EIS measurements

Fig.11 shows the Nyquist diagrams of specimens measured in artificial seawater. It is noticeable that there is one semicircle over the measuring frequency range at E_{corr} for the samples corroded in immersion and tidal zones after both the first day and fifth day, however two semicircles can be observed on the 10th day.

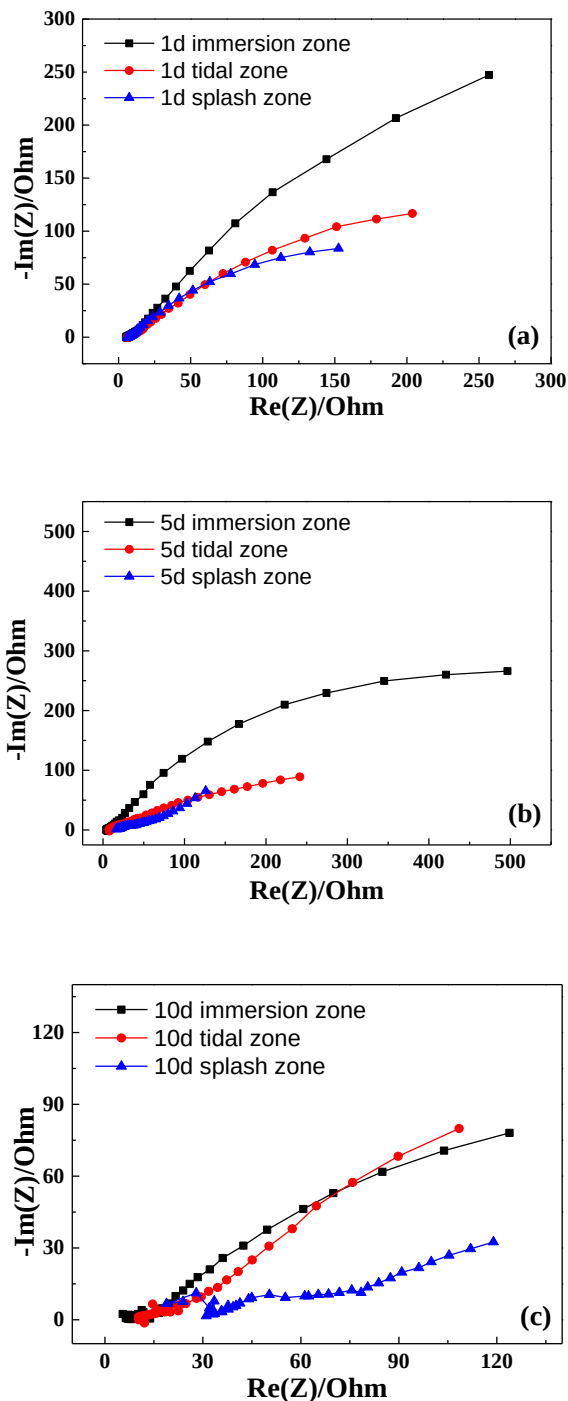


Figure 11. Nyquist diagrams of Q235 steel samples in various simulated marine zones after different exposure periods in the simulation and acceleration test device. (a)1d; (b)5d; (c)10d.

It is seen further from the EIS spectra of Fig.11 that in splash zone, the Nyquist curve has two semicircles on the fifth day and the real ohm increases with the decrease in frequency and forms a straight line with an angle of about 45° , indicating the existence of diffusion resistance layer at the electrolyte-substrate interface. However, diffusion resistance layer disappears and the second semicircle can be observed on the 10th day. The reason may be the impact of wave striking, which wash the corrosion products away and other phases generate. Furthermore, the radius of the semicircle

decreases with the test duration. Semicircles of Nyquist curves for specimens in splash zone show the smallest radius, indicating that the lowest corrosion resistance of the specimens in this zone[25]. Electrochemical impedance spectroscopy can be fitted with model I in Fig. 12 for the initial corrosion behavior.

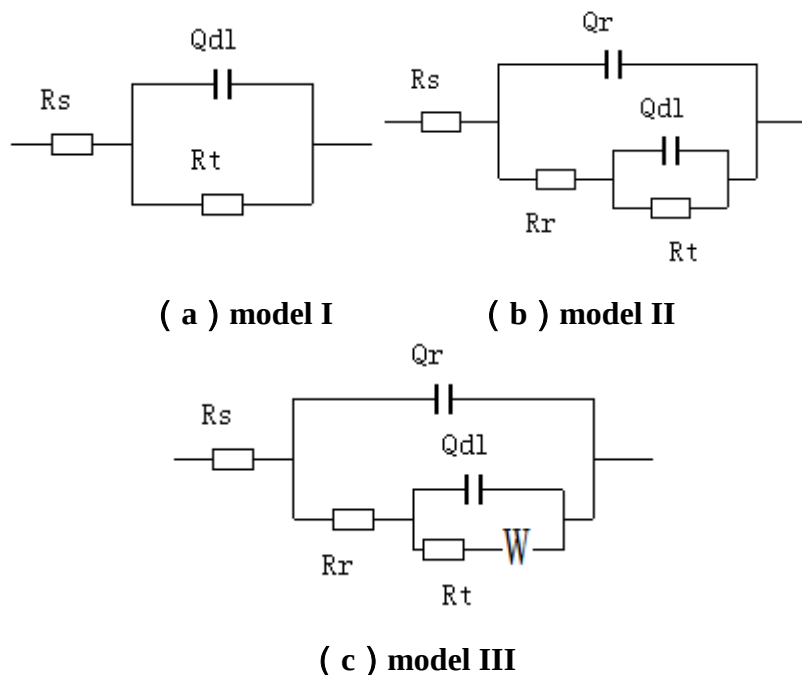


Figure 12. Equivalent circuits for fitting the EIS results of Q235 steel samples after different exposure periods in Fig.11

Table 4. The fitted values of various electrical components evaluated from EIS shown in Fig 10

Marine zones	Time	Q_r ($\Omega^{-1} \cdot \text{cm}^{-2} \cdot \text{s}^{-n_r}$)	n_r	R_r ($\Omega \cdot \text{cm}^2$)	Q_{dl} ($\Omega^{-1} \cdot \text{cm}^{-2} \cdot \text{s}^{-n_{dl}}$)	n_{dl}	R_t ($\Omega \cdot \text{cm}^2$)	W ($\Omega \cdot \text{cm}^2 \cdot \text{s}^{-1/2}$)
Immersion	1d	7.505×10^{-3}	0.6061	4.897	9.287×10^{-3}	0.7545	1226	—
Tidal		4.857×10^{-3}	0.5568	3.688	8.426×10^{-3}	0.6295	1374	—
Splash		8.496×10^{-3}	0.5129	4.9	1.026×10^{-2}	0.6906	329.4	—
Immersion	5d	1.856×10^{-4}	1	15.14	6.056×10^{-3}	0.6521	655	—
Tidal		4.192×10^{-5}	0.913	13.17	7.224×10^{-3}	0.3556	669.6	—
Splash		4.197×10^{-3}	0.2036	16.34	6.356×10^{-4}	0.6896	32.48	0.04991
Immersion	10d	1.357×10^{-4}	0.3943	18.31	1.267×10^{-2}	0.6808	968.7	—
Tidal		5.964×10^{-3}	0.4681	15.77	2.869×10^{-2}	0.5424	410.7	—
Splash		3.952×10^{-3}	0.3211	30.72	3.803×10^{-3}	0.4488	199.8	—

With the extension of time, a continuous layer of corrosion products generated on the substrate and the spectra can be fitted with model II in Fig. 12. In splash zone, model III is used for the existence of diffusion resistance layer. In Fig.12, it is obvious that the semicircles are distorted. Therefore, constant phase elements(CPE) are used to accurately analyze the electrode reactions.

The fitting curves can match the original experimental curve perfectly and the corresponding fitted data are shown in Table 4. Here R_r , Q_r , R_t , Q_{dl} and W represent respectively for rust layer resistance(R_r), constant phase element(Q_r), charge-transfer resistance(R_t), double-layer capacitance (Q_{dl}), warburg diffusion resistance (W). The high frequency semicircle reflects the corrosion behaviors on the interface between solution and corrosion products. The low frequency semicircle is related to the electrode reactions on the interface between substrate and corrosion products[c]. It is evident from the Table 4 that R_r in different marine zones is basically the same in each cycle. However, R_t in splash zone has less resistance than that in other zones, which is the reason specimens in marine splash zone corrode more seriously. Though R_r increases, the reduction of inner rusts makes the electrode reactions on the interface between substrate and corrosion products more easily, resulting in the decrease of R_t .

4. CONCLUSIONS

1. The order of corrosion rate for specimens by individually hanging in developed marine corrosion simulation and acceleration test device is $v_{\text{splash zone}} > v_{\text{tidal zone}} > v_{\text{immersion zone}} > v_{\text{atmospheric zone}}$ and the order of corrosion rate for specimens by electrically connected hanging specimens is $v_{\text{splash zone}} > v_{\text{immersion zone}} > v_{\text{tidal zone}} > v_{\text{atmospheric zone}}$, which were consistent with corrosion rates obtained in the actual marine environment.

2. The corrosion products of Q235 carbon steel formed in every corrosive zone are all divided into two layers after indoor simulated and accelerated corrosion. The outer layers are brownish yellow, loose and easy to remove meanwhile the inner layers are black, dark and combined tightly with the metallic substrate.

3. The results of XRD patterns show that the rust formed on the Q235 carbon steel is substantially the same in different corrosive zones and mainly composed of α -FeOOH, γ -FeOOH, Fe_3O_4 , $\text{Fe}(\text{OH})_3$, $\text{Fe}_8(\text{O},\text{OH})_{16}\text{Cl}_{1.3}$.

4. The maximum corrosion rate of Q235 carbon steel for indoor simulated corrosion test is in the splash zone and up to 1.5mm/a. Compared with the actual marine environment corrosion, the corrosion rate of Q235 carbon steel for all marine zones has a certain degree of acceleration performance. The acceleration ratio is about 1.5~4.3 times.

The above indicated, the developed simulative and accelerative marine corrosion device not only has excellent simulation of the major parameters and conditions in various marine zones, but also has a good acceleration performance. As a consequence, this method can greatly shorten the actual marine environment corrosion test period.

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