Corrosion Behavior of 316L Stainless Steels Exposed to Salt Lake Atmosphere of Western China for 8 years

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Abstract

The evolution of corrosion behavior of 316L stainless steels exposed to salt lake atmosphere for 8 years was investigated. The results showed that the stainless steel in salt lake atmosphere had a greater corrosion rate during the initial exposure time and relatively lower corrosion rate during the subsequent exposure time. Dust depositions accumulated on the downward surface caused severe local corrosion of stainless steel. As exposure time prolonged, the relative amount of Cr_{oxide} and Fe_{oxide} in the corrosion products gradually increased, which may directly affect the corrosion rate of stainless steels. Moreover, the maximum pit depth followed a power function with respect to exposure time.

Keywords Atmospheric corrosion · Salt lake atmosphere · Stainless steel · X-ray photoelectron spectroscopy (XPS) · Electrochemical impedance spectroscopy (EIS)

1 Introduction

Stainless steels demonstrate high degree of corrosion resistance, widely used for exterior of buildings exposed to various atmospheric environments. However, stainless steels would inevitably suffer severe local corrosion such as pitting corrosion, particularly in marine atmosphere containing chloride environment, leading to materials failure with pronounced adverse consequences in economy and safety [1–4]. Therefore, it is important to study about the corrosion behavior of stainless steels in marine atmosphere. Many researches have been carried out based on the field exposure experiment or indoor accelerated test. Lv et al. investigated

the evolution of 316L stainless steels subjected to a simulated marine atmosphere and concluded that the initiation of pitting corrosion was associated with MnS dissolution and the depth of pits increased with the extending of corrosion time [5]. Burkert et al. compared and assessed the corrosion behaviors of nine types of stainless steels exposed to marine environment as long as 5 years [6]. Tong et al. investigated the corrosion behaviors of austenitic steels exposure to marine atmosphere of the South China Sea, and the results showed that the average corrosion rate of stainless steels was about 0.1–1 $\mu\text{m a}^{-1}$ [7].

Salt lakes are abundant in mineral resources. (For instance, salt lakes hold more than 70% of global Li reserves in store, which is the key point for the development of Li battery) [8, 9]. Many countries including China pay more and more attention to the development and utilization of salt lakes. There are hundreds of salt lakes widely distributed in the northwest of China, which belong to the typical arid and salt-rich environments and are usually rich in MgCl₂. In addition, the average amount of Cl[−] is 34 wt%, which is 10 times more than those in seawater. It is well known that the atmospheric corrosion occurs owing to the interactions of materials with climatic factors, and the corrosion rate of atmospheric corrosion is related to the pollutant present in atmosphere and the wetting time, i.e., the time and frequency of wetting the metal surface and the drying rate [10–14]. Thus, the climatic difference may cause distinct corrosion

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behaviors of metals exposed to salt lake atmosphere and marine atmosphere. According to the corrosion survey in western China, the corrosion behaviors of some common metals such as carbons, weathering steels and aluminum alloys exposed to salt lake atmosphere are quite different from those exposed to marine atmosphere [15, 16]. However, relatively little work has been carried out on stainless steels; thus, it is of great significance to investigate the corrosion behavior and corrosion mechanism of stainless steels in salt lake atmosphere.

Stainless steels will rapidly form a thin passive film on the surface when exposed to the atmosphere. The properties and the stability of passive film determine the corrosion resistance of stainless steels in different environments. However, when the passive film is destroyed, the pitting corrosion may occur and the corrosion products are formed on the surface of stainless steels [17–19]. Asami and Hashimoto [20] reported that the corrosion resistance of stainless steels was strongly related to the content of Cr in corrosion products. Tian et al. [21] reported that the metastable pits' growth was controlled by the diffusion of corrosion products. Dong et al. [22] observed that the number and depth of pits increased along with the increase in surface coverage of corrosion products. Zhang et al. [23] considered that the corrosion products covered the pits in the early stage of pitting, while the growth rate of pits greatly reduced due to the decrease in Cl^- and OH^- ions concentration after removing the corrosion products. The above results showed that the composition and evolution of corrosion products played an important role in corrosion process, which also affected the subsequent corrosion behavior of stainless steels.

Accordingly, this work focuses on the corrosion behavior and mechanism of 316L stainless steels exposed to salt lake atmosphere for 0.5, 1, 2, 4 and 8 years. For this purpose, the morphology and composition of corrosion products, weight loss, statistics of maximum of pitting pits and electrochemical experiment were investigated. The results obtained by field condition could reflect the comprehensive effect of the environments, which can be used to evaluate the longevity of metals in natural salt lake atmosphere and provide a scientific basis for the design and protection for the rational selection.

2 Experimental

2.1 Materials Preparation

316L stainless steel was selected as the test material, and its composition is listed in Table 1. The four parallel specimens (three for gravimetric measurement and one for rust layer analysis) were cut into sizes of 100 mm × 50 mm × 3 mm. Specimens for electrochemical measurements were cut into sizes of 10 mm × 10 mm × 3 mm and mounted in epoxy resin leaving an exposure area of 1 cm². The specimens for electrochemical measurements were ground on emery paper successively to 1000#. All the specimens were ultrasonically cleaned with acetone, rinsed with alcohol, and then dried in the desiccator for 48 h in order to evaporate the water. After the treatment, the specimens for gravimetric measurements were weighed using an analytic balance (with the precision of 0.0001 g).

2.2 Outdoor Exposure and Climatic Characteristics of Exposure Site

The field exposure site was located in Geermu district, northwest of China, with great difference in temperature, longer sunshine time, less precipitation, larger evaporation and about 30% of annual average relative humidity. The detailed environmental parameters around the salt lake are listed in Table 2. The exposure site was located on the roof of a storage about 40 m far away from the salt lake. The specimens were fixed facing south at an angle of 45° to the horizon under open conditions. Test specimens were retrieved from the test site for analyses after 0.5, 1, 2, 4 and 8 years of exposure for each test period, from 2004 to 2012.

2.3 Gravimetric Measurement

Corrosion products of specimens withdrawn from each test site every period were removed chemically by pickling in the specific solution (100 mL nitric acid + 900 mL distilled

Table 1 Chemical compositions of the 316L stainless steel (wt%)

C	Si	Mo	S	P	Cr	Ni	Fe
0.03	1.00	2.5	–	–	17	12.3	Bal.

Table 2 Regional climatic factors of the exposure site

Region	Average wind velocity (m s ⁻¹ year ⁻¹)	Average temperature (°C year ⁻¹)	Average sunshine duration (h year ⁻¹)	Average precipitation (mm year ⁻¹)	Average evaporation (mm year ⁻¹)	Average humidity RH (%)
Geermu	3–4	4.2	3073.3	38.6	2306.8	34

water) for about 20 min at 60 °C according to the International Organization for Standardization (ISO) 8407 standard. The process was repeated three times and recorded the specimen mass after each procedure. Meanwhile, the mass loss of uncorroded specimens caused by pickling was also determined. Then, the specimen mass loss was determined after taking both the weight loss of exposed specimens and that of uncorroded specimens into account. The experimental error was controlled less than 3% and not more than 9%.

2.4 Analysis of Corrosion Products and Pitting

The macro-morphologies of the surfaces of stainless steels were observed by a digital camera (Nikon D50) after the specimens were extracted from salt lake atmosphere. At the same time, the scanning electron microscopy (SEM, XL30 FEG) was used to observe the surface and cross-sectional micro-morphologies of the corrosion products. For cross-sectional morphologies analysis of the specimens, nickel was deposited on the surface to enhance the protection of the rust layer, and then fixed with epoxy resin, mechanically ground down to 2000 grit SiC paper and polished with 2.5 μm diamond paste. The energy-dispersive spectroscopy (EDS) was used to determine the elemental composition and elemental distributions of the cross-sectional morphologies. In addition, the 3D morphologies and pit depth statistics were observed using a white-light interferometer (MicroXAM) after removing the corrosion products. The pit density (%), the ratio of pitting to sample area, was counted by the image analysis software (Image J).

The X-ray photoelectron spectroscopy (XPS, ESCALAB 250) depth profile measurements were performed on specimens for analysis of chemical composition of corrosion products. The core-level spectra of the main elements in the alloy and the O 2p and C 1s spectra were recorded with monochromatic Al K α (1486.6 eV) radiation. The measured specimen current was 2 μA , and the bombardment area was dimensions of 2 mm $\times$ 2 mm.

2.5 Electrochemical Measurements

The electrochemical impedance spectroscopy (EIS) of the exposed specimens was conducted with an electrochemical workstation (PARSTAT 2273) in a conventional glass cell, using the platinum plate as counter electrode and a saturated calomel reference electrode (SCE). The measurements were carried out in a 0.1 mol L⁻¹ Na₂SO₄ solution. In the case of EIS measurements, the amplitude of the AC voltage was 10 mV and the frequency range changed from 10⁵ to 10⁻² Hz. The frequency scanning was always performed in a direction from high to low frequency. Prior to EIS measurements, the samples were immersed freely in the solution for 3600 s to attain a stable open circuit potential. The EIS data were analyzed with ZSimpWin software.

3 Results and Discussion

3.1 Corrosion Rate

Weight loss measurement is the most direct and accurate method to determine the corrosion rate. Figure 1 gives the corrosion rate of 316L stainless steels calculated by weight loss data as a function of exposure time. As can be seen, the corrosion rate of 316L stainless steels declined with exposure time and tended to be stable after 4 years of exposure. In other words, the stainless steel has a greater corrosion rate during the initial exposure time, and a lower corrosion rate during the subsequent exposure time in salt lake atmosphere.

3.2 Morphologies Analysis of Corrosion Products

Figure 2 shows the macro-morphologies of stainless steels after exposure in salt lake atmosphere for 0.5, 1, 2, 4 and 8 years. After 0.5 years of exposure, the upward surface of stainless steel was completely covered with loose dark brown corrosion products as dots or flakes that were easily removed. After exposure time of 1 year, the corrosion products formed on upward surface of stainless steel became lighter in color and difficult to scrape. As exposure time continued further, the downward surface suffered more severe local corrosion compared with the upward surface of stainless steels. There was a lot of soil and the pitting corrosion visible to the naked eye on the downward surface of stainless steels which may be due to less solar radiation and rain-washed action. (Unless otherwise specified, the following surface of stainless steels means the upward surface).

Figure 3 displays a series of SEM images showing the evolution of corrosion products formed on stainless steels after exposure of 0.5, 1, 2, 4 and 8 years. It can be seen that some bright corrosion products appeared on the sample

Fig. 1 Corrosion rate of 316L stainless steel after different exposure time in salt lake atmosphere, from 2004 to 2012 at Geermu, China

Fig. 2 Evolution of the surface of 316L stainless steel exposed to the salt lake atmosphere as a function of exposure time

surface after 6 months of exposure. However, as the exposure time progressed, the bright corrosion products gradually disappeared and many pits were formed near the bright

corrosion products. The EDX was employed to analyze the composition of the bright area and the dark area on the surface of stainless steels exposed to salt lake atmosphere

Fig. 3 Evolution of SEM micro-morphologies of corrosion products formed on 316L stainless steel as a function of exposure time: **a** 0.5 years, **b** 1 year, **c** 2 years, **d** 4 years, **e** 8 years

for 1 year, and the results are shown in Table 3. The foreign depositions such as O, Cl, S, Si, Al, Ca, Mg, Na and K elements were all detected in both bright area and dark area. It was worth noting that the amount of O, Cl, Si, Ca elements in bright area was higher than that in dark area, while the amount of Fe, Cr, Ni elements in bright area was lower than that in dark area, indicating more depositions in bright area. The above results indicated that pitting may preferentially initiate near the dust deposition areas. This is because the electrolyte films containing chloride tend to maintain in gaps caused by dust deposits, preventing the supply of oxygen, leading to the dissolution of passivation film and promoting the occurrence of pitting corrosion [24]. Besides, the deposited dust (mainly composed of SiO_2 , CaCO_3) may cause severe bruises and scratches by the power of wind, which is easy to cause the occurrence of pitting on the surface of specimens, because the scratches are prone to generate electrolyte droplet and thin liquid layer [25, 26]. Compared with the upward surface, more dust depositions, which are difficult to be washed away by wind and rain, were deposited on the downward surface of stainless steels, and then resulted in serious pitting corrosion on the downward surface of stainless steels.

The cross-sectional morphology on the upward surface of the samples and the distributions of the main elements such as O, Fe, Cr, Ni and Si in the rust layer after 8 years of exposure are displayed in Fig. 4. It can be seen that the thickness of the corrosion products was nearly 10 μm , indicating that the stainless steels exposed to salt lake atmosphere

suffered severe corrosion. The element distribution maps indicated that O, Fe and Cr elements were uniformly distributed throughout the corrosion products, and they were mixed with the dust depositions such as Si in the corrosion products.

3.3 Analysis of Pits Morphology and Depth

SEM and the white-light interferometer (MicroXAM) were respectively used to analyze the evolution of 2D and 3D of the surface micro-morphologies of stainless steels after removing the corrosion products after 0.5–8 years of exposure in salt lake atmosphere, as shown in Fig. 5. It was obvious that few pits seemed to form during the initial 0.5 years of exposure. However, the number of pits gradually increased with the extending of exposure time. In addition, from the white-light interferometer images, we can see clearly that the depth of the pit formed on stainless steel surface also gradually increased as the exposure progressed.

It is considered that the maximum pit depth formed on the surface of stainless steel is closely related to the safety of stainless steel in service [27]. Thus, the relationship between the maximum pit depth and the exposure time was also analyzed by the white-light interferometer (MicroXAM) according to a statistical analysis method. Figure 6a presents the evolution of the largest pit depth formed on the specimens as a function of exposure time. As can be easily seen in Fig. 6a, the maximum pit depth increased gradually with increasing exposure time. The

Table 3 Elements contents in the corrosion product (wt%) on 1 year stainless steel surface

Area	O	Na	Mg	Al	Si	S	Cl	K	Ca	Cr	Fe	Ni
In bright area	11.63	2.75	4.48	3.98	13.13	1.07	23.20	2.59	8.11	5.214	20.84	6.72
In dark area	4.61	3.16	2.56	4.14	10.56	1.58	14.49	1.47	3.22	10.07	34.66	9.17

Fig. 4 Element distribution of the cross-sectional morphology on the upward surface of 316L stainless steel after 8 years of exposure

Fig. 5 Evolution of SEM and white-light interference pictures of 316L stainless steel after removing corrosion products as a function of exposure time: **a** 0.5 years, **b** 1 year, **c** 2 years, **d** 4 years, **e** 8 years

maximum pit depth formed on stainless steels was about 28 μm after 0.5 years of exposure in salt lake atmosphere, whereas the pit depth was nearly 60 μm after 8 years of exposure. According to the corresponding fitting results, the maximum depth of pits shows a power function on the increase of exposure time. $n < 1$ indicated the pits grew faster in the initial exposure time, and the increase rate of pit depth decreased with the extending of exposure time, which was also consistent with the results characterized by mass loss. Besides, Fig. 6b shows the evolution of the pit density as a function of exposure time. It was obvious that the change trend of the pit density has similar variations as that of the pit depth.

It is known that the corrosion resistance of 316L stainless steel is better than that of 304 stainless steels.

However, it is reported that the maximum pit depth formed on 304 stainless steels is about 25 μm after 2 years of exposure [28], while the maximum pit depth formed on 316L stainless steels after 2 years of exposure is nearly 45 μm in the present study. Therefore, it can be concluded that the corrosion rate of stainless steel exposed to salt lake atmosphere was higher compared to that exposed to marine atmosphere.

3.4 Composition of Corrosion Products

It is considered that the composition of corrosion products is closely related to the subsequent corrosion behavior of metal [29, 30]. Therefore, it is necessary to obtain the information of composition evolution of corrosion products on the surface of stainless steels exposed to salt lake

Fig. 6 Maximum pit depth **a** and pit density **b** of the 316L stainless steel in salt lake atmosphere as a function of exposure time

atmosphere. However, it is impossible to obtain the composition of corrosion products using X-ray diffraction due to the low amount of corrosion products formed on the surface of stainless steels; thus, XPS measurement was performed to gain more information about the composition of corrosion products formed on stainless steels. Figure 7 displays the XPS spectra after 1080 s of sputtering of 316L stainless steels exposed to salt lake atmosphere for 0.5, 2 and 8 years, respectively, especially showing the Fe $2p_{3/2}$, Cr $2p_{3/2}$ and O $1s$ core-level spectra. It was observed that the composition of corrosion products formed on stainless steels exposed to salt lake atmosphere did not change with the extending of exposure time. The fitting curves of the peak binding energies indicate that Fe is present in states as Fe (metal), Fe(II) oxide, Fe(III) oxide and Fe(III) hydroxide with the binding energies of 707.5, 709.4, 710.7 and 711.7 eV, respectively (Fig. 7a) [31]. However, the peak at 714.3 eV has no corresponding substance. Based on the researches on the corrosion of steel exposed to salt lake atmosphere [15, 16], the substance at 714.3 eV can be assigned to LDH-Cl (layered double hydroxides) [32], a special corrosion product formed on steel in the environment containing $MgCl_2$. Cr is present as Cr (metal), Cr(III) oxide, Cr(III) hydroxide and

Cr(VI) oxide at 574.6, 576.4, 577.4 and 578.8 eV, respectively (Fig. 7b). The O $1s$ peaks were mainly attributed to O^{2-} (530.3 eV), OH^- (531.2 eV) and H_2O (532.5 eV), which play an important role of connecting metal ions (Fig. 7c).

It is reported that the OH^- -rich part of passive film has a stronger buffer effect against chloride attack than the O^{2-} -rich part. However, the ionic bond between O^{2-} and metal ions in the metal oxide layer is less attacked by chloride than that between the OH^- and metal ions [18, 33]. From this viewpoint, the relative amount of $[O^{2-}]$ and $[OH^-]$ in the corrosion products have been calculated, respectively, and the results are shown in Fig. 8a. As seen from figure, they showed an increasing trend and decreasing trend, respectively, which indicated that the oxide in the corrosion products was gradually becoming a major component with the extending of exposure time, while the proportion of hydroxide in corrosion products was becoming less and less. The relative amount of [hydroxide] and [oxide] of the main alloy elements Cr and Fe in corrosion products are further calculated in Fig. 8b, c. It can be seen that the relative amount of $[Cr_{hyd}]$ in the corrosion products gradually decreased as a function of exposure time in Fig. 8b. $Cr(OH)_3$ can be regarded as an unstable structure,

Fig. 7 XPS spectra after 1080 s of sputtering observed for 316L stainless steel in salt lake atmosphere after 0.5 years, 2 years and 8 years exposure in Fe $2p_{3/2}$ **a**, Cr $2p_{3/2}$ **b**, O $1s$ **c**

Fig. 8 Evolution of the relative amounts of [hydroxide] and [oxide] of O, Cr and Fe in corrosion products formed on 316L stainless steel in salt lake atmosphere as a function of exposure time

which cannot improve the corrosion resistance, leading to the reduced protectiveness of corrosion products and pitting resistance according to the previous researches [34, 35]. However, the relative amount of $[\text{Cr}_{\text{ox}}]$ in corrosion products formed on stainless steels gradually increased as a function of exposure time. Cr_2O_3 , due to its dense structure, could significantly improve the corrosion resistance of stainless steels in the service environment [36, 37].

Figure 8c gives the relative amounts of $[\text{Fe}_{\text{hyd}}]$ and $[\text{Fe}_{\text{ox}}]$ in corrosion products. It could be seen that the change trend of the relative amount of $[\text{Fe}_{\text{hyd}}]$ and $[\text{Fe}_{\text{ox}}]$ has similar variations as that of $[\text{Cr}_{\text{hyd}}]$ and $[\text{Cr}_{\text{ox}}]$. As the exposure time progressed, the relative amount of $[\text{Fe}_{\text{ox}}]$ gradually increased, while the relative amount of $[\text{Fe}_{\text{hyd}}]$ contained in corrosion products gradually decreased. The reason for the change trend may be related to the following corrosion reactions [38, 39]: During the initial state or when the corrosion products formed on stainless steels were very small, anodic dissolution of steel and cathodic reduction of oxygen are the dominant corrosion processes. At this time, dissolved Fe^{2+} were hydrolyzed into a deposit of $\text{Fe}(\text{OH})_2$ and quickly oxidized to $\text{Fe}(\text{OH})_3$ as the corrosion process proceeds. $\text{Fe}(\text{OH})_3$ was further converted into an amorphous deposit of FeOOH . It is generally accepted that the initial oxyhydroxide product was $\gamma\text{-FeOOH}$. During the corrosion process, $\beta\text{-FeOOH}$ may also be formed with the deposition of chlorinated salts. From the electrochemical point of view, both the $\gamma\text{-FeOOH}$ and $\beta\text{-FeOOH}$ are active and they can be easily reduced to Fe_3O_4 and intermediates. As the exposure time processed, more and more dense corrosion products such as Cr_2O_3 formed on the surface of stainless steels and limited the supply of O_2 to some extent, the anodic dissolution of substrate was mostly balanced by the following cathodic reduction but not by oxygen:

As a result, as the exposure time progressed, the relative amount of $[\text{Fe}_{\text{ox}}]$ gradually increased and the relative amount of $[\text{Fe}_{\text{hyd}}]$ contained in corrosion products gradually decreased. The increase in the relative amount of Cr_{oxide} and Fe_{oxide} improved the protectiveness of the corrosion products, further leading to the decrease in the corrosion rate of stainless steels with the increasing of exposure time.

3.5 EIS Results

In order to evaluate the protectiveness of corrosion products formed on stainless steels exposed to salt lake atmosphere during different exposure periods, electrochemical measurement was carried out. Figure 9a and b represents the Nyquist and Bode diagrams of unexposed and preexposed samples in $0.1 \text{ mol L}^{-1} \text{ Na}_2\text{SO}_4$ as a function of exposure time. It is

acknowledged that the diameter of capacitive arc represented the corrosion resistance of the material in the solution and the corrosion resistance increased with the increase in the diameter [40, 41], so it can be obtained that the corrosion resistance of stainless steels increased with extension of the exposure time.

The equivalent electrical circuit, shown in Fig. 9c, is utilized to fit the EIS data and account for the atmospheric corrosion behaviors of stainless steels. The elements used in the equivalent circuit are as follows: Q_r and R_r are used to describe the dielectric properties of the corrosion product layer, and Q_{dl} and R_{ct} represent the charge transfer process. R_s represents the electrolyte resistance. The fitting parameters for stainless steels are listed in Table 4. Obviously, the value of R_{ct} gradually increases with the increasing exposure time. R_{ct} reflects the inhibition of the charge transfer process. According to the results shown in Figs. 2 and 3, it was observed that more and more corrosion products were formed on the surface of stainless steels as the exposure time progressed. In addition, the relative amount of protective product Cr_2O_3 gradually increased, while the non-protective product $\text{Cr}(\text{OH})_3$ gradually decreased, as shown in Fig. 8b, c. All of that could effectively resist the invasion of corrosion media, thus blocking the charge transfer process and resulting in an increase in R_{ct} . In the previous studies, $1/R_{\text{ct}}$ can be calculated to characterize the corrosion rate of metals, because R_{ct} is determined only from faradaic processes controlled by the charge transfer-controlled corrosion. Figure 9d reflects the evolution of $1/R_{\text{ct}}$ as a function of exposure time. Obviously, the initial value of $1/R_{\text{ct}}$ decreases significantly and then tends to be stable, which is pretty consistent with the trend of corrosion rate calculated by mass loss measurement (shown in Fig. 2).

3.6 Effect of the MgCl_2 on the Corrosion Behavior of Stainless Steels

Atmospheric corrosion of metal is significantly affected by time of wetness, which not only depends on the relative humidity and the environmental temperature but also on the presence of atmospheric pollutants such as chlorides. Deliquescence is a process in which solid salts absorb water vapor to form a liquid electrolyte, which occurs at or above a specific RH value, the DRH. For the reverse process, the RH of deliquesced solution crystallization is called the efflorescence relative humidity (ERH). In salt lake region where the field exposure testing was conducted, it is rich in MgCl_2 . As the deliquescence relative humidity (DRH) and efflorescence relative humidity (ERH) values of MgCl_2 are much lower than that of NaCl [42–44], which implies that the time of wetness of stainless steel exposed to the actual salt lake atmosphere (mainly containing MgCl_2) was much longer than that exposed to actual marine atmosphere (mainly containing NaCl) during a wet/dry cycle. Therefore, the corrosion

Fig. 9 Electrochemical test results of 316L stainless steel as a function of exposure time in 0.1 mol L⁻¹ Na₂SO₄ solution: **a** Nyquist diagrams, **b** Bode diagrams, **c** equivalent circuits, **d** reciprocal of R_{ct}

Table 4 Fitting results of EIS parameters

Parameters	R_s (Ω cm ²)	Q_r		R_r (Ω cm ²)	Q_{dl}		R_{ct} (Ω cm ²)
		y_r (Ω^{-1} cm ⁻² S ⁻ⁿ)	n_r		y_{dl} (Ω^{-1} cm ⁻² S ⁻ⁿ)	n_{dl}	
0 (year)	22.5	1.61×10^{-5}	1	14.03	3.64×10^{-5}	0.843	2.3×10^5
0.5 (year)	25.9	4.05×10^{-5}	0.893	14.97	1.54×10^{-5}	0.784	4.14×10^5
1 (year)	24.7	3.92×10^{-5}	0.819	16.2	1.35×10^{-5}	0.915	5.17×10^6
2 (year)	29.7	1.54×10^{-5}	0.899	35.2	1.62×10^{-5}	0.881	7.71×10^6
4 (year)	23.7	1.72×10^{-5}	0.828	69.3	2.79×10^{-5}	0.844	1.22×10^7
8 (year)	28.7	1.74×10^{-5}	0.825	252	1.39×10^{-5}	0.87	2.36×10^7

rate of 316L stainless steel exposed to salt lake atmosphere was higher compared with that exposed to marine atmosphere reported by Dong et al. [22]. However, during the whole corrosion process, the relative amount of Fe_{ox} and Cr_{ox} in the corrosion products formed on stainless steel surface increased with the extension of the exposure time, which improved the protectiveness of the corrosion products, representing the decrease in the corrosion rate.

In addition, LDH-Cl may be formed in the corrosion products, which was detected in the XPS analysis. It is known that pH (8–10) and supersaturation of the solution are two key factors in the synthesis of LDH [45–47]. Firstly, as most of MgCl₂ existed, the solution formed on sample surface was usually saturated. And secondly, the corrosion of stainless steel exposed to natural salt lake atmosphere can result in the formation of Fe(OH)₃; meanwhile, along

with pH increasing of localised areas where provide sites for oxygen reduction, brucite $\text{Mg}(\text{OH})_2$ precipitated. Both two key factors could be met in the corrosion process of stainless steel exposed to salt lake atmosphere. That is to say, after a series of complex reaction steps between $\text{Fe}(\text{OH})_3$ and $\text{Mg}(\text{OH})_2$, LDH-Cl is likely to form. However, in the present work, the existence of LDH-Cl cannot be directly proved by XRD analysis due to the low amount of corrosion products formed on stainless steel surface. In the future work, the laboratory simulation test method will be used to verify further the existence of LDH-Cl and study the influence of LDH-Cl on the corrosion behavior of stainless steel.

4 Conclusions

The atmospheric corrosion behavior of 316L stainless steels exposed to salt lake atmosphere environment for 0.5–8 years has been studied. The following conclusions can be drawn from the above experimental results:

1. The corrosion process of stainless steels in salt lake atmosphere for 0.5–8 years can be divided into two periods with a greater corrosion rate during the initial exposure time and a lower corrosion rate during the subsequent exposure time.
2. The downward surface of stainless steels suffered more severe corrosion compared with the upward surface, which may be due to more dust depositions that are difficult to be washed away by rain and wind.
3. The increase in the relative amount of Cr_{oxide} and Fe_{oxide} was conducive to improve the protection performance of corrosion products, resulting in the decrease in the corrosion rate of 316L stainless steel.
4. The number and depth of pits increased with the extending of exposure time, and the maximum pit depth followed a power function.

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