

Research Article

Synergistic Effect of Carbamide and Sulfate Reducing Bacteria on Corrosion Behavior of Carbon Steel in Soil

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Synergistic effect of carbamide and sulfate reducing bacteria (SRB) on corrosion behavior of carbon steel was studied in soils with moisture of 20% and 30%, by soil properties measurement, weight loss, polarization curve, and electrochemical impedance spectroscopy. The results show that carbamide decreased the soil redox potential and increased soil pH. In soil without SRB, carbamide made corrosion potential of Q235 steel much more positive and then inhibited corrosion. Meanwhile, in soil with SRB, 0.5 wt% carbamide restrained SRB growth and inhibited biocorrosion of Q235 steel. Corrosion rate of carbon steel decreased in soil with 30% moisture compared with that with 20% moisture.

1. Introduction

Soil corrosion is one of most common corrosion behaviors of metals underground. There are numerous factors influencing the soil aggressiveness such as soil humidity, acidity, soil salinity, and composition of microbes [1–4]. These factors interchange over time, making soil corrosion study much more complicated. The idea that soil corrosion depends on such factors as soil resistivity [2], pH [5], redox potential [6], water content [7, 8], and sulfate reducing bacteria (SRB) [9, 10] is widely accepted and studied. pH, soil acidity, is a comprehensive reflection of soil chemical properties, especially the salt content. It affects both anode and cathode polarization process, which are related to corrosion dynamics [5]. It is well known that metals suffer serious corrosion in strongly acidic environment. Since in strongly acidic soil, with decreasing pH, the depolarized potential of hydrogen increases, consequently corrosion rate increases. Meanwhile in soils with a high content of organic matters and organic acid, even with pH being neutral, metals can still suffer serious corrosion [11].

The soil redox potential reflects various kinds of oxidation-reduction equilibrium, normally changing from

+700 mV to -300 mV. It is mainly affected by soil salt composition and content, aeration condition, organic matter, and so on. A soil with strong reducing property is commonly considered as a reference index of biocorrosion [12]. The main kinds of microbe related to soil corrosion include aerobic corrosion bacteria, such as sulfur-oxidizing bacteria and iron bacteria, and anaerobic corrosion bacteria such as SRB, referred to as Microbiological Influenced Corrosion (MIC) [13, 14]. Of various types of microorganisms, anaerobic SRB are the most common ones that induced MIC of underground pipeline steel [15]. Many studies have investigated SRB induced corrosion of carbon steel in soil simulation solution [3, 16].

The soil corrosiveness increases with soil moisture [12, 17]. But when saturated the diffusion of oxygen would be suppressed. Besides, soil moisture depended on local climate. In Shenyang, north part of China, the average soil moisture is 20%. Few studies have been done on the corrosion behavior of carbon steel in saturated soil [18, 19]. In addition, most of the studies on soil corrosion were conducted in soil simulated solution [20], ignoring some soil factors. For example, large amount of nitrogenous fertilizer has been used on farmland for agriculture development, of which carbamide is the most

TABLE 1: Compositions of the soil (mg/100 g soil).

chemical composition								organic content	whole nitrogen content	total salt content	pH
NO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺				
4.6	3.1	4.8	23.4	5.7	3.2	0.2	1.4	2260	91	46.4	7.75

TABLE 2: Experimental matrix.

Experiments	Soil A	Soil B	Soil C	Soil D
Soil moisture (wt.%)	20%	20%	30%	30%
Carbamide (wt.%)	0.5 wt%	0.5 wt%	0.5 wt%	0.5 wt%
Activated SRB	No	Yes	No	Yes

common type. It would be of importance to study the effect of carbamide on metals underground. However, little work has been done. Carbamide is able to be adsorbed on the steel surface to inhibit its corrosion [21]. There are also reports that carbamide can be used as a noncorroding alternative to rock salt for road deicing. In addition, it has been applied as corrosion inhibitor in metal pickling.

Besides, nitrogen is one of the essential elements to constitute protein and nucleic acid for bacteria in soil. Hence carbamide can serve as nitrogen source for SRB growth. The synergistic effect of carbamide and sulfate reducing bacteria (SRB) on corrosion behavior of carbon steel in soils will be interesting. In our previous work [19], the low content of carbamide promoted the growth of SRB and prevented the microbiological corrosion of Q235 steel. In this work, further studies in different soil moisture of 20% and 30% are done to see the effect of excess carbamide on SRB growth and on biocorrosion behavior of carbon steel.

2. Experimental Design

2.1. Materials and Preparation

2.1.1. Coupon Preparation. Carbon steel Q235, with a composition (wt.%) of 0.30 C, 0.019 P, 0.029 S, 0.01 Si, 0.42 Mn, and balance Fe, was cut into two varied sizes, 10×10×3 mm and 20×20×3 mm, which will be used as working and counter electrodes and weight-loss test samples. The coupons were abraded with a series of grit papers (200, 400, 600, 800, and 1000) followed by cleaning in acetone and alcohol and then dried. The working and counter electrodes were embedded in epoxy resin to give working areas of 10 mm × 10 mm for electrochemical measurements in a three-electrode cell. The working surface was cleaned with acetone and distilled water. All the prepared coupons were sterilized under ultraviolet rays prior to each experiment.

2.1.2. Soil Preparation. The chemical compositions of soil used in this work are given in Table 1. The soils were sterilized by heating at 121.8°C at high pressure. Then the sterilized soil and distilled water were mixed proportionally in experimental containers, to make different soils with moisture content of 20% and 30%.

2.1.3. Carbamide and SRB. Carbamide was purchased from Sinopharm, with the nitrogen content of 46.4 wt.% according to the national standard GB2440-2001. Before experiment set-up, different amounts of carbamide were measured by electronic analytical balance up to 0.0001 g, sterilized under ultraviolet rays, and mixed into different soils prepared above.

The sulfate reducing bacteria (SRB) used in this study are *Desulfovibrio desulfuricans*, same SRB strain as described in previous paper [20, 22]. SRB cultures were incubated in an anaerobic environment in the API RP-38 medium (g/l), containing MgSO₄·7H₂O 0.2, KH₂PO₄ 0.5, NaCl 10.0, ascorbic acid 1.0, sodium lactate 4.0, yeast extract 1.0, and Fe(NH₄)₂(SO₄)₂ 0.02. The pH value of the culture solution was between 7.0 and 7.1. SRB species were activated in an incubator for 24 hours and then were added to and mixed carefully with the prepared soil under bubbling N₂ in the experiment container. Then, the experiment containers were weighted and sealed over experiment period to keep the water moisture constant. The experimental matrix is listed in Table 2.

2.2. Testing Environments and Methods. All the experiments were performed at room temperature for 65 days.

2.2.1. Soil Redox Potential and pH. Soil redox potential was measured by a multimeter, 5 Pt electrodes, and a saturated calomel electrode (SCE). The redox potential was calculated from

$$E_h = E_m + 250 + 60 * (pH - 7) \text{ (mV)} \quad (1)$$

where E_h is redox potential at pH=7 (mV, standard hydrogen scale); E_m is the mean of the potential measured from the five platinum electrodes (mV) [23]. Soil pH was also measured from time to time, using the same method as in published article [22].

2.2.2. Immersion Tests. The specimens of 20×20×3 mm were used for weight-loss tests, which were buried at a depth of 10 cm below the surface of the soils in the same experimental containers. The prepared specimens were weighed to a precision of 0.1 mg before tests. After the experiment, the extracted specimen was pickled in a mixture containing hydrogen

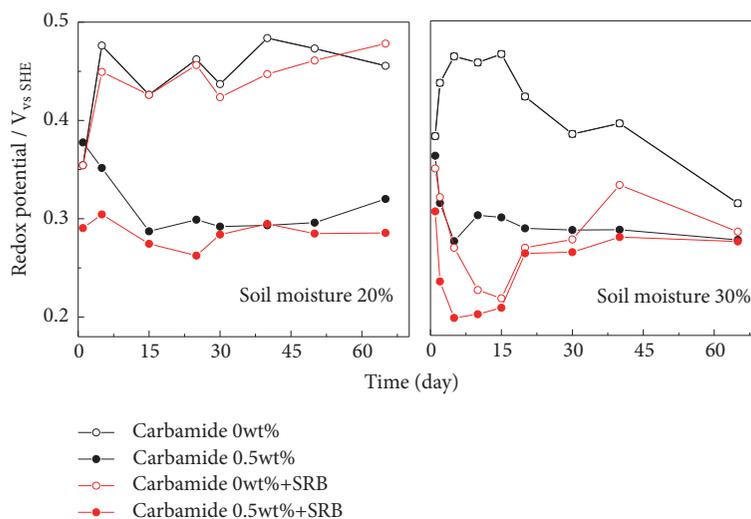


FIGURE 1: The soil redox potential changes over time.

chloride (HCl) 500 ml, urotropine 20 g, and water (H₂O) 500 ml for 10 min at room temperature, then cleaned with water, dried at 105. 8°C for 30 min in a furnace, cooled, and weighed. The same process was repeated until the difference between the last two results was less than 0.0001 g. Weight losses were calculated and converted into uniform corrosion rates ($\mu\text{m}/\text{y}$). Each experiment used triplicate specimens to guarantee the reliability of the results. After the tests, surface appearance of tested specimen was observed using scanning electron microscopy (SEM).

2.2.3. EIS and Polarization Tests. Electrochemical tests were performed in a three-electrode system, with a graphite electrode used as the counter electrode, a saturated copper/bluestone (Cu/CuSO₄) electrode as the reference electrode, and carbon steel as working electrode. The tests were conducted using the PARSTAT 2273 electrochemical measurement system. In EIS, an alternating current signal with a frequency range from 10 kHz to 1 mHz and an amplitude of 10 mV was applied to the working electrode at the corrosion potential. Potentiodynamic polarization was tested at the potential scanning velocity 0.5 mV/s and with the scope being ± 0.25 V.

3. Results and Discussion

3.1. Soil Properties. The changes of soil redox potential over time are shown in Figure 1. Obviously in soils with and without SRB, the addition of carbamide made the soil redox potential decrease dramatically. That is because carbamide increased the soil organic matter content. The redox potential was more negative in soil with SRB, in agreement with published literature [22]. It is commonly accepted that the more negative the soil redox potential, the more the aggressiveness the carbon steel suffered [12]. However, this may not be the case in neutral or alkaline soil: the more positive the soil redox potential is, the more serious the steel would suffer. Hence soil

pH needs to be measured over time. Effect of soil moisture on soil redox potential was also compared in Figure 1. The redox potential in soil moisture of 30% was lower than that in soil moisture of 20%. That is because the more the water content, the lower the oxygen level in soil.

As mentioned above, pH is an important parameter to measure soil corrosivity. Hence, the changes of soil pH were recorded and drawn in Figure 2. pH value in soils with carbamide is much higher than in soils without carbamide, where the fact that some carbamide was decomposed into carbon dioxide (CO₂) and ammonia (NH₃) makes sense. When NH₃ volatilized, pH declined slightly after 35 days, as shown in Figure 2. Considering the effect of SRB, pH value was a little bit lower in soil with SRB. This is because the ultimate metabolic product of SRB was low-carbon chain fatty acid, which formed relative acid environment [24, 25]. Some studies have shown that metabolic products of bacteria can promote corrosion of carbon steel in soil. In soil with moisture of 30%, compared to 20%, pH value decreased in soil with carbamide and increased in soil without carbamide.

So, the addition of carbamide decreased soil redox potential and made the soil pH higher than 7, which theoretically decreases the soil corrosivity and then inhibits corrosion behavior of carbon steel. Meanwhile, the addition of SRB in soil decreased soil redox potential, and soil pH was lower than 7 in soil moisture of 20% and neutral in 30% moisture, generally increasing the soil corrosivity and accelerating corrosion of carbon steel. The synergistic effect of carbamide and SRB on corrosion behavior of carbon steel in soil will be very interesting, considering that carbamide can be the growth resource of SRB.

3.2. SRB Growth Analysis. To check the effect of carbamide on SRB growth, different addition levels of carbamide were studied in soil, shown in Figure 3. The method of how to detect the number of live SRB has been published in our previous work [20, 22], which follows the national standard

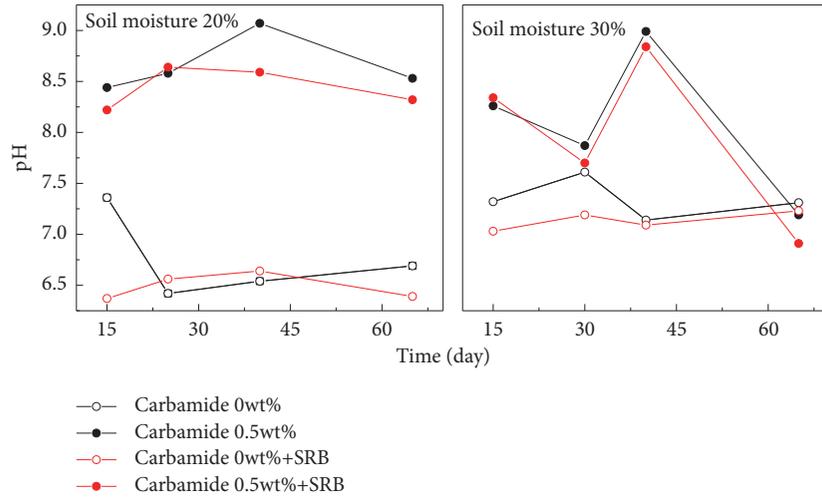


FIGURE 2: Soil pH changes over time.

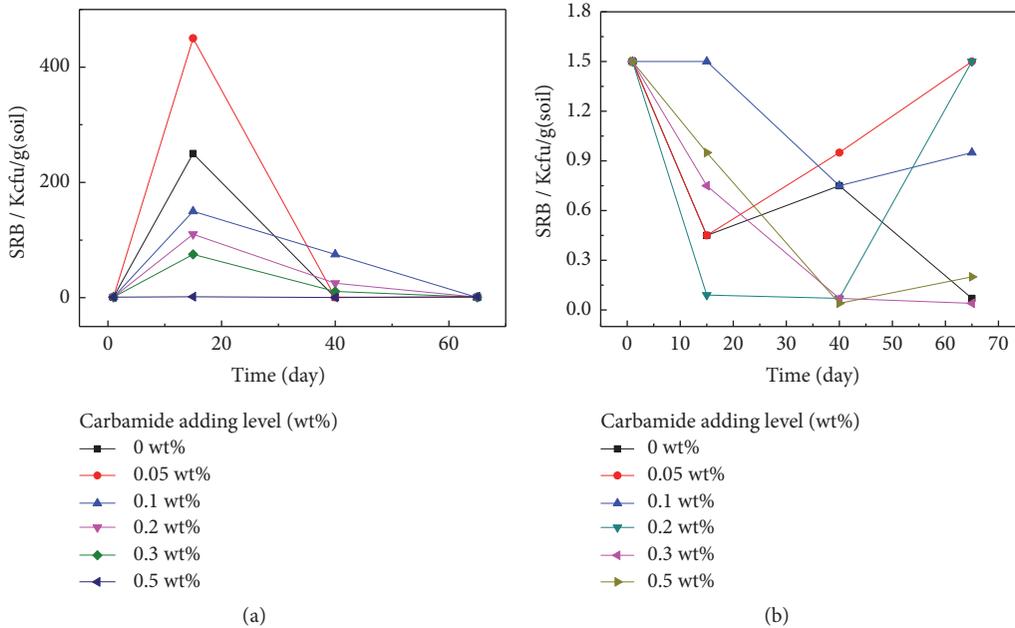


FIGURE 3: Number of SRB over time in soil with moisture of 20% (a) and 30% (b).

[26]. In the early stage of the experiment, the amount of SRB in soils with low content of carbamide is more compared with higher carbamide. Over time, due to the decomposition of the carbamide, the soils with higher level of carbamide have more live SRB, but significantly lower than the initial number. This indicated that carbamide promoted the growth of SRB but in a certain limited level. With excess amount of carbamide, SRB growth was compressed. With soil moisture of 30%, the amount of SRB decreased first and then increased, and the changes of SRB were different in soils with different concentrations of carbamide. In general, low content of carbamide promoted SRB growth, while elevated levels of carbamide (0.5 wt%) inhibit the growth of SRB, same as the result in 20% moisture.

3.3. *Corrosion Potential of Carbon Steel.* The corrosion potential of carbon steel fluctuated at an initial period due to the unstable soil environment (Figure 4). After 10 days, it kept constant. In soils without SRB, corrosion potential of carbon steel was more positive in soil containing carbamide than that in soil without carbamide. Carbamide was easily adsorbed on the steel surface to form a protective film [6]. However, when the soil environment was unstable, the adsorbed film was incomplete and corrosion potential tended to be more negative. When the soil environment was stable, corrosion potential dramatically increased in soil with carbamide, which indicated that carbamide inhibited steel corrosion. Meanwhile, in soil with SRB, corrosion potential tended to be negative in soil with carbamide, the reason for which

TABLE 3: Fitting results of polarization curves.

Fitting results of polarization curves		0 wt%		0.5 wt%		0 wt%+SRB		0.5 wt%+SRB	
		I_{corr} ($\mu\text{A}/\text{cm}^2$)	E_{corr} (mV)						
Soil moisture 20%	1 day	1.552	-556.6	35.42	-689.9	0.6235	-781.7	2.561	-798.6
	40 days	9.063	-486.5	2.227	-324.0	1.280	-890.3	0.7698	-891.2
	65 days	6.745	-489.7	0.5043	-277.0	3.899	-897.9	2.178	-822.8
Soil moisture 30%	1 day	9.068	-786.6	51.64	-821.1	5.083	-823.9	2.129	-823.9
	40 days	2.440	-638.8	0.3075	-214.4	5.222	-869.3	3.089	-319.9
	65 days	3.252	-780.0	1.284	-242.9	0.5128	-918.7	4.096	-224.4

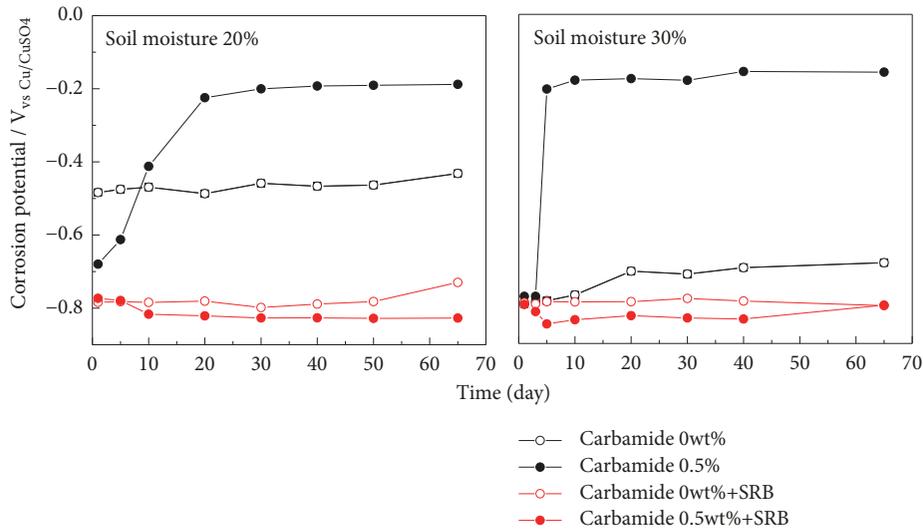


FIGURE 4: Corrosion potential of Q235 steel over buried time.

was discussed before. Proper amount of carbamide provided energy for the growth of SRB and promoted soil corrosion of carbon steel. Hence the effects of carbamide on soil corrosion turned to its effects on SRB growth. But excessive carbamide decreased the number of SRB, which in turn inhibited soil corrosion of Q235 steel. To compare corrosion potential in different soil moisture, there were minor changes except that in soil without carbamide. In that experiment group, corrosion potential of Q235 steel in soil with moisture of 30% was more negative than that in soil with moisture of 20%. Probably the increased water molecule reduced the corrosion potential, which played no role in soil with carbamide.

3.4. Polarization Curves of Carbon Steel. The polarization curves of carbon steel Q235 in different soils after 1 day, 40 days, and 65 days are shown in Figures 5 and 6, respectively, and the fitting results are listed in Table 3. At day 1, in contrast with the groups in soils without carbamide, corrosion current I_{corr} was larger and corrosion potential E_{corr} was more negative in soil with 0.5 wt% carbamide. That is likely due to the incomplete protective film which would cause localized corrosion on steel surface. In soil with SRB, I_{corr} of Q235 steel was smaller than that in soils without SRB, since initially the

biofilm of SRB was formed on the sample surface to protect it from corrosion [20]. In soil with moisture of 30%, I_{corr} increased over all.

Over time, E_{corr} of Q235 steel in soil without SRB shifted to be positive, and I_{corr} decreased. Because initially oxygen depolarization was the leading cathodic reaction, over time oxygen was consumed and cathode reaction was prevented. Besides the slope of anodic polarization became larger, which shows that there were corrosion products on the steel surface, and the diffusion process of cation became more difficult. Comparing with the case in soils without carbamide, E_{corr} of carbon steel in soil with carbamide was more positive and I_{corr} was much lower, indicating that carbamide inhibited corrosion reaction of carbon steel. In soil with moisture of 30%, the slope of cathode polarization curve was even smaller, showing the cathode reaction was inhibited, and I_{corr} was decreased. Besides, E_{corr} shifted to be more negative, which agrees with published literature [8]. In soil with SRB, E_{corr} was much more negative than that in soils without SRB. I_{corr} increased after 40 days except the group in soil with moisture of 30% and containing 0.5 wt% carbamide. I_{corr} increased because of the death of SRB and the degradation of SRB metabolite products. It has been reported that corrosion

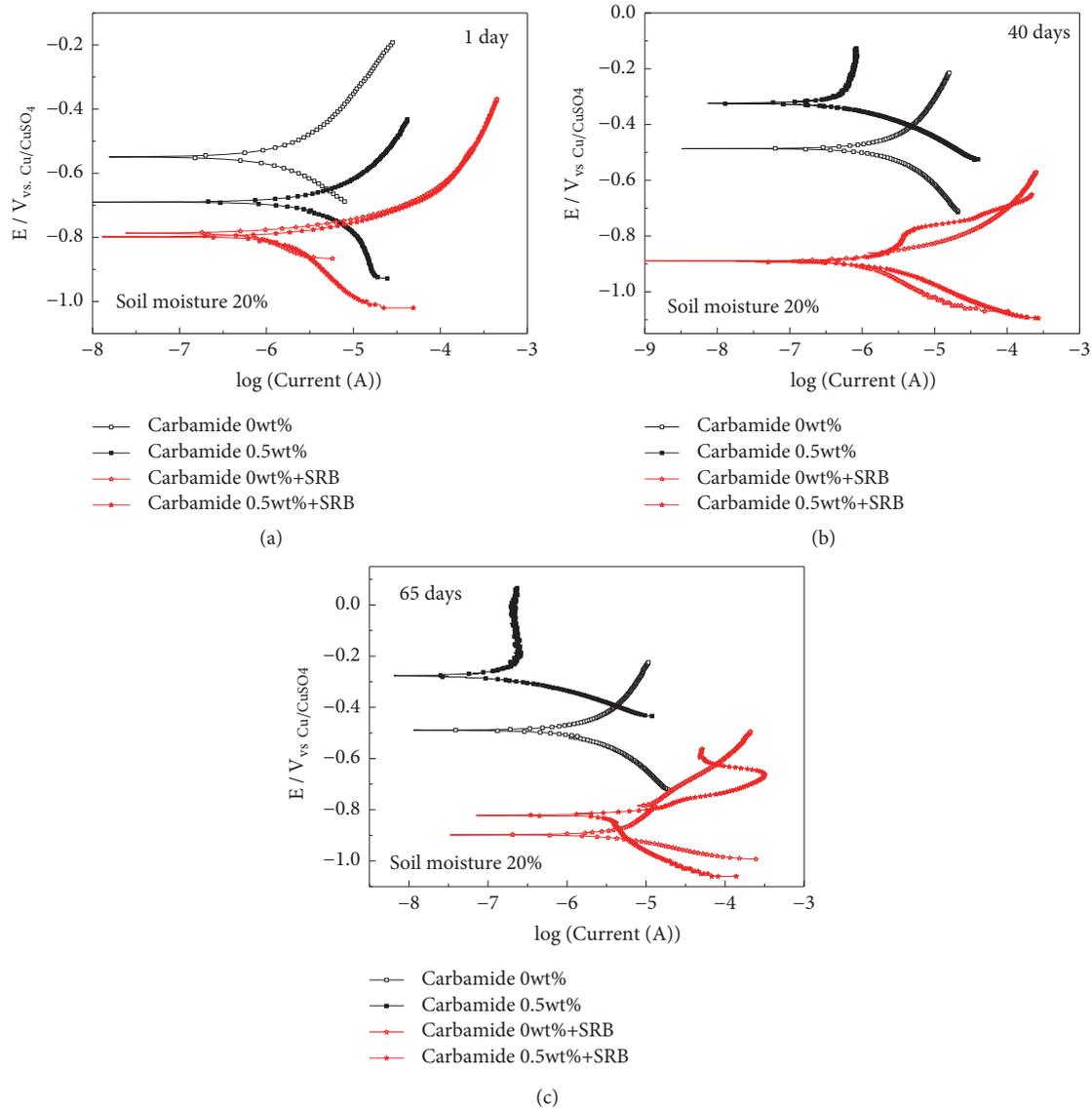


FIGURE 5: Polarization curves of Q235 steel in soil with moisture of 20% after 1 day (a), 40 days (b), and 65 days (c), respectively.

rate of Q235 steel was enhanced in the death phase of SRB [27]. In soil containing 0.5 wt% carbamide, there appeared passivation but soon activation on the anodic polarization plot, which was due to the formation and fracture of mixed products on the steel surface. The cathodic curves became flat, showing that the reduction of corrosion products was prevented.

After long term experiments (see 65 days), in soil without SRB, the anode Tafel slope was dramatically larger than the cathode Tafel slope, which indicates that the corrosion rate was controlled by the anode process [28]. This is probably because the corrosion products prevent the dissolution of the iron. In soil moisture of 20% current rate was declined, and in soil moisture of 30% current rate instead increased slightly possibly because of the rupture of corrosion products. The current rate in soil containing 0.5 wt% carbamide was

dramatically smaller than that in soil without carbamide. In soils with SRB, the anode process was passivated due to its corrosion products on the surface. But still corrosion rate was larger than that in soil without SRB, which indicates that SRB and its metabolite promoted corrosion of Q235 steel.

3.5. Analysis of the Electrochemical Impedance Spectroscopy (EIS). EIS was one of the effective means to investigate the electrochemical properties of the corroded surface of carbon steel in soils. However, soil environment is very complicated, and corrosion products of carbon steel usually combine with soil particles closely, which make EIS plots hard to analyze and various analysis methods have been proposed [29, 30]. To be sample, in the Bode plots, the impedance modulus at the high/medium frequencies reflects the resistance of all products on the steel surface, and that at the low frequencies

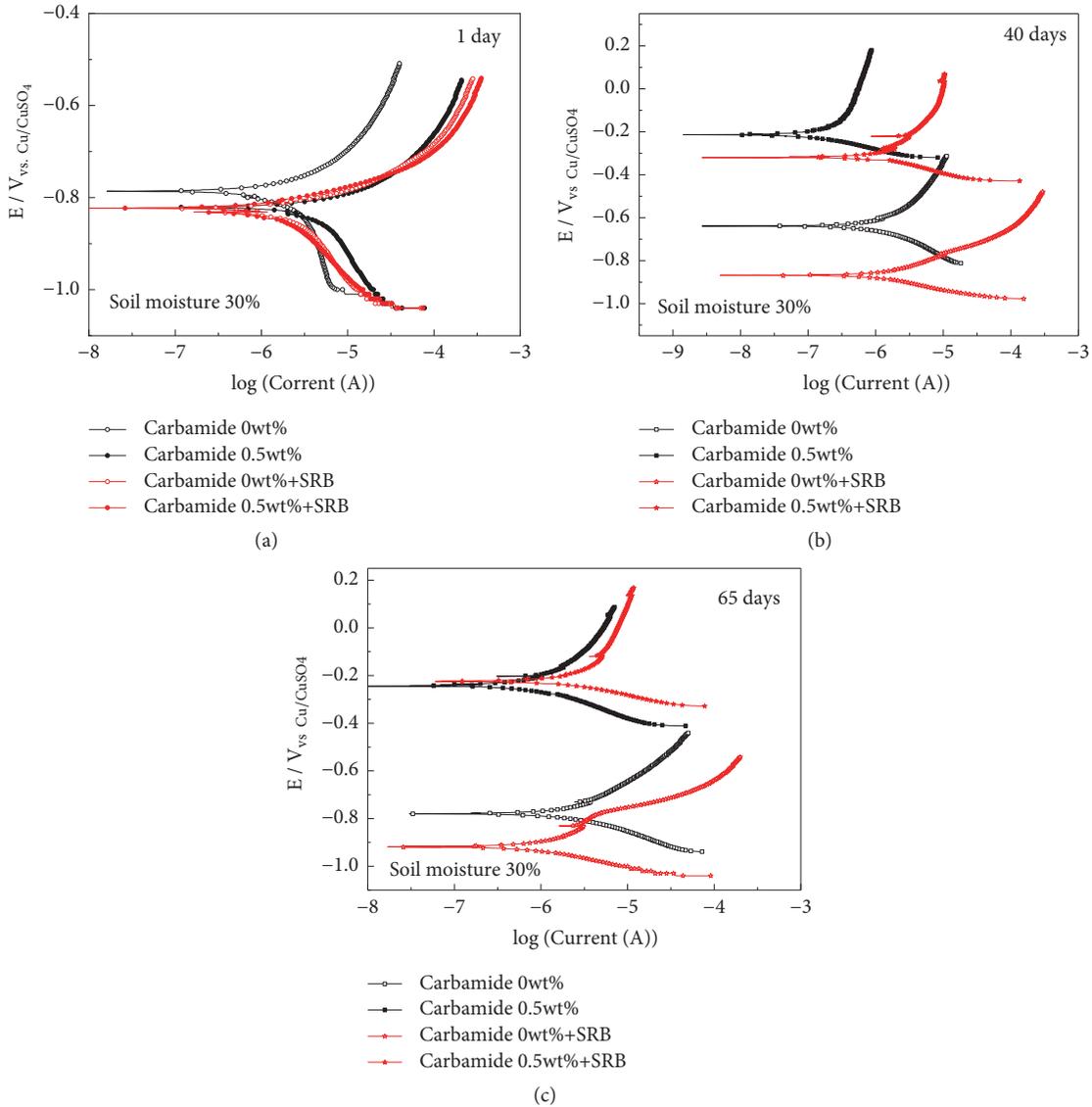


FIGURE 6: Polarization curves of Q235 steel in soil with moisture of 30% after 1 day (a), 40 days (b), and 65 days (c), respectively.

reflects the charge transfer resistance related to the iron dissolution reaction. Figures 7 and 8 show EIS Bode plots of the carbon steel Q235 in soils with moisture 20% and 30% after 3 days, 30 days, and 65 days, respectively.

After 3 days, there was few corrosion products on the steel surface, so the resistance at high/medium frequency was generally low in all experiment groups. In soil with moisture of 20%, the resistance at low frequency in soils containing 0.5 wt% carbamide was smaller than that in soil without carbamide, which was due to the same reason as before. Carbamide was adsorbed on the steel surface to form an incomplete film, which promoted the charge transfer. In soils with SRB, at the initial period carbamide and SRB were both adsorbed on the steel surface to form a protective film, so the resistance at the low frequency in soil added carbamide was larger than that in soil without carbamide, in accordance with the results of polarization curves. In soil with moisture of

30%, whether in soils with and without SRB, charge transfer resistance in soil containing carbamide was lower than that in soil without carbamide, indicating carbamide inhibited the corrosion reaction. Besides, the impedance at low frequency was smaller than that in soil with moisture of 20%.

After 30 days, there were corrosion products on the steel surface; thus the resistance at the high/medium frequencies increased. One or two time constants were found in the plots, which was dependent on the combination of corrosion products on the sample surface, which can be confirmed by SEM and EDS data, shown in Figure 11. But the corrosion products combined with soil grains were easily broken off, which shows that the resistance at the high frequency cannot reflect the real resistance of corrosion process. The resistance at the low frequency instead shows the corrosion situation more accurately. In soil with moisture of 20%, the resistance at the low frequency increased in soils without SRB and

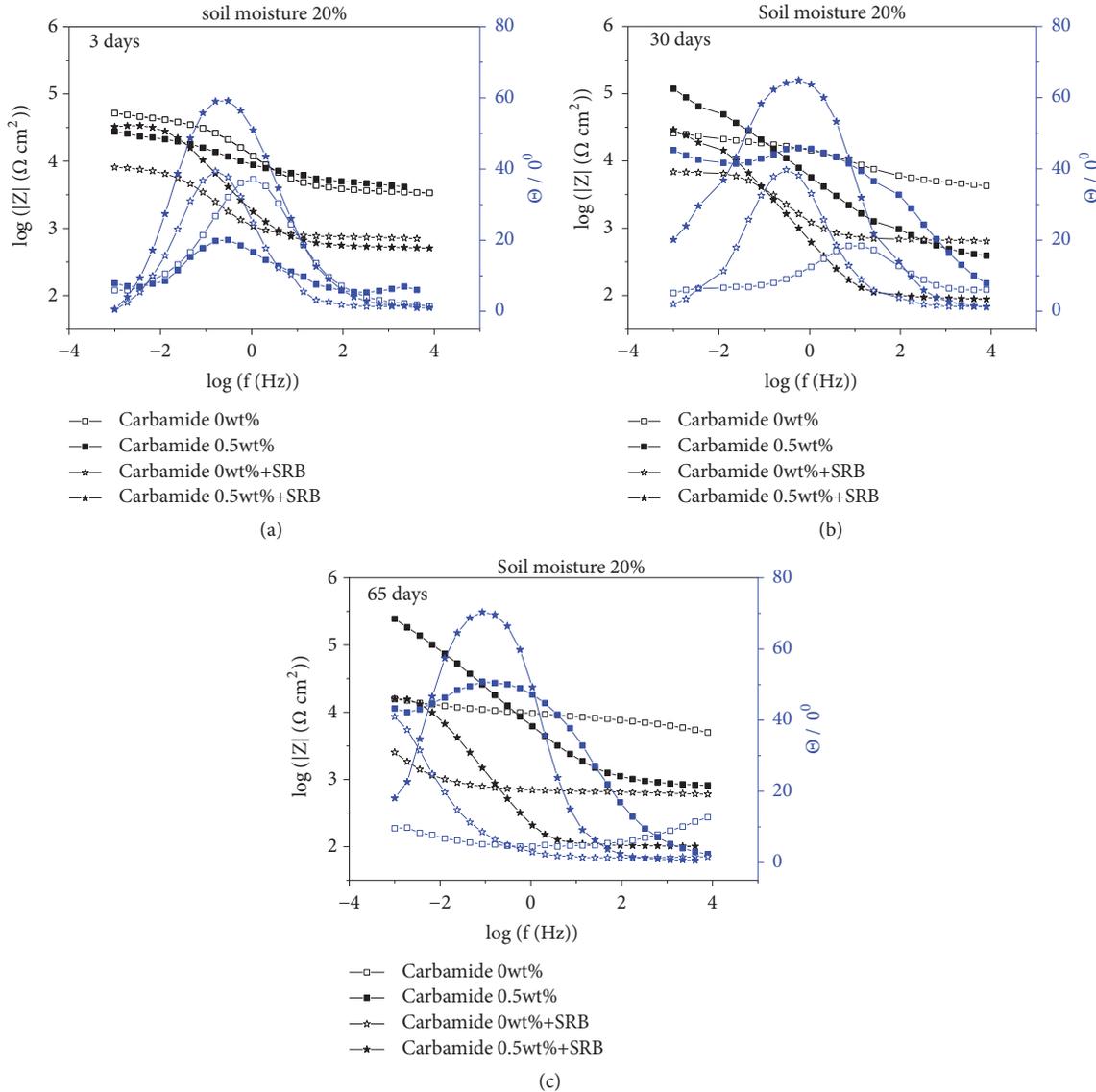


FIGURE 7: EIS plots of the carbon steel Q235 in soils with moisture of 20 wt% after 3 days (a), 30 days (b), and 65 days (c).

decreased in soils with SRB which was in accordance with the results of polarization curves. In soil moisture of 30%, the resistance at the low frequency increased due to the corrosion products on the steel surface. The charge transfer resistance in soil added carbamide was larger than that in soil with no carbamide, which indicates that carbamide could inhibit the further corrosion in soil. Over time, there were more and more corrosion products on the surface of carbon steel and then the diffusion of corrosion products became more difficult. Hence, after 65 days, there was Warburg impedance in EIS plot, which indicates that the process was controlled by concentration polarization [31].

In addition, electric equivalent circuits (EEC) models were selected to fit EIS data of carbon steel in soils with moisture 20 wt%, shown in Figure 9. R_s represents the soil electrolyte resistance, and R_f represents all the resistance

of products on the surface of sample. R_t and Q_{dl} represent the charge transfer resistance and the double layer capacitance, and W represents the Warburg impedance. Then the corrosion resistance R_{cr} was calculated to be the sum of R_f , R_t , and diffusion resistance W_R , to check the evolution of carbon steel in different soils over time. The SEM and EDS data were drawn to show the surface morphologies of carbon steel in soils with moisture 20 wt% (Figure 11). It can be seen from Figure 10 that initially R_{cr} was similar in all soils except in soils with no carbamide but with SRB. In soils with no carbamide but with SRB, R_{cr} was higher, in agreement with the polarization test. Over time, the R_{cr} value of carbon steel in soils with SRB decreased, and localized corrosion was overserved on surface (Figure 11(a)). At 15 days, in soils with SRB, localized corrosion occurred, while the element S was detected at the location where

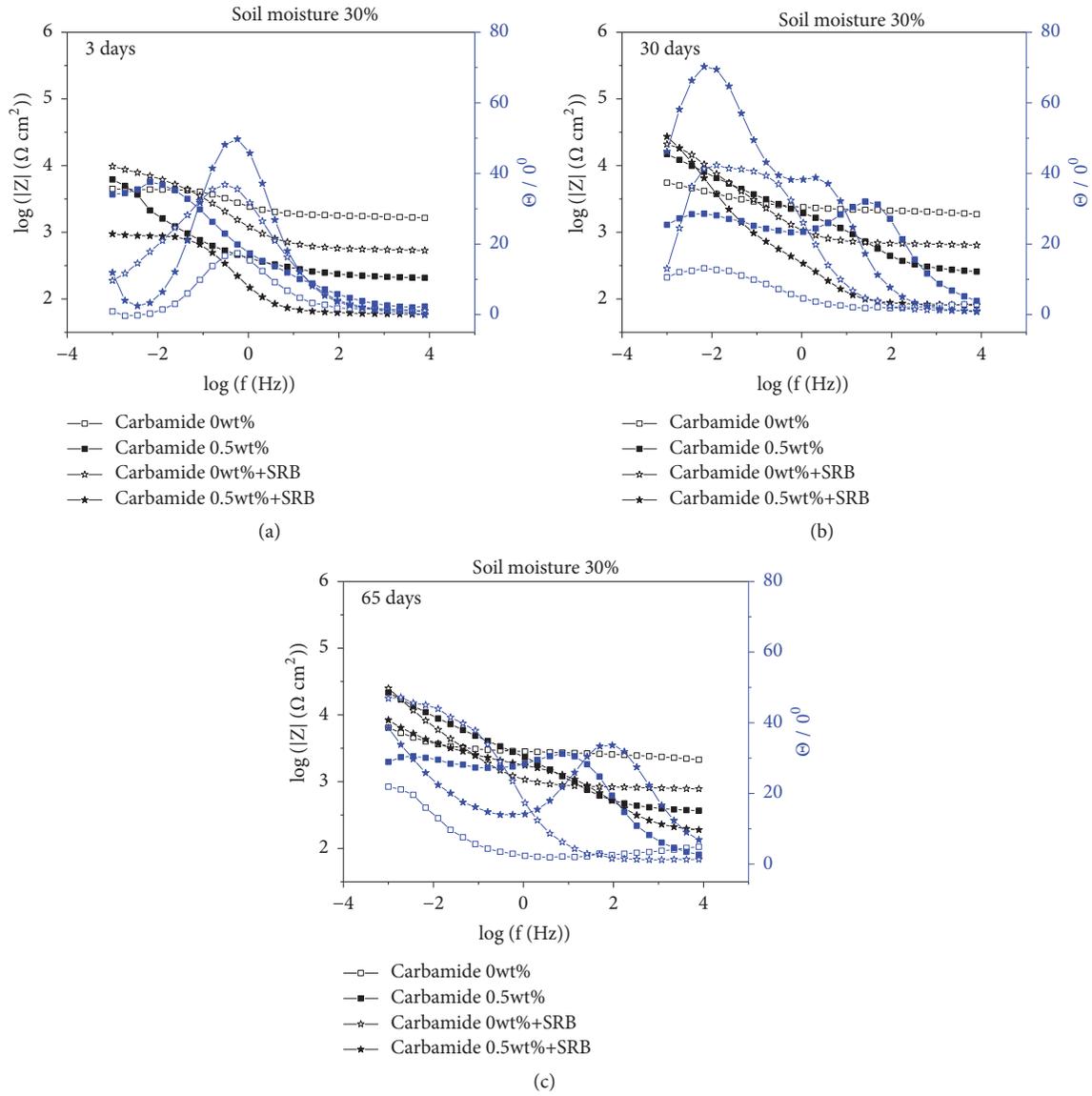


FIGURE 8: EIS plots of the carbon steel Q235 in soils with moisture of 30 wt% after 3 days (a), 30 days (b), and 65 days (c).

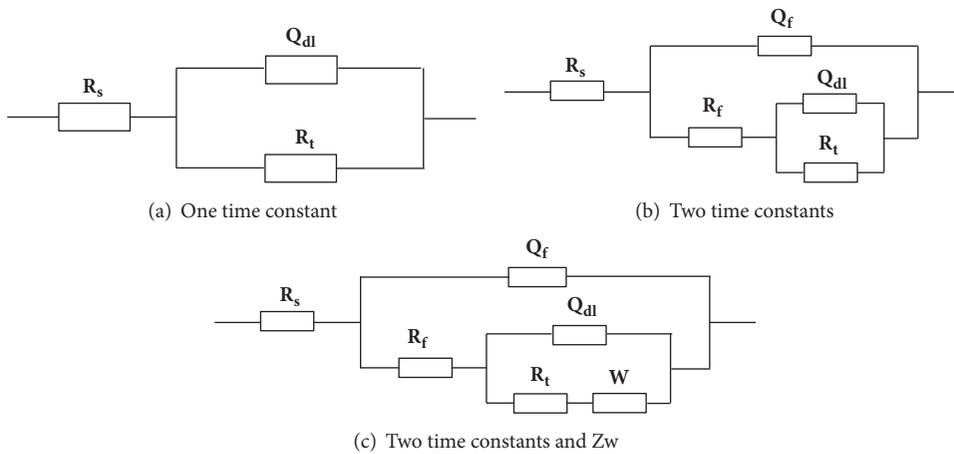


FIGURE 9: Equivalent circuits of the different time constants.

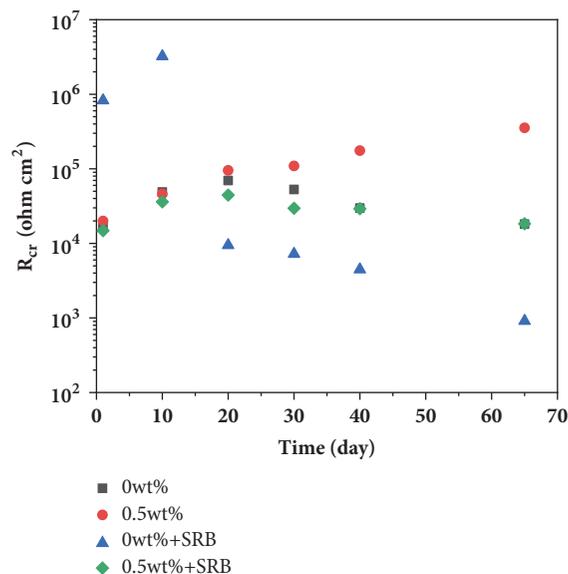


FIGURE 10: EIS fitting parameter R_t changes over time in different systems.

SRB was detected (Figure 11(b)). After 65 days, localized corrosion was also detected on the sample surface and SRB metabolic products combined with corrosion products and soil particles were observed (Figures 11(c) and 11(d)). R_{cr} of carbon steel in soils with carbamide was higher than that without carbamide, indicating carbamide inhibited corrosion reaction of iron. After 65 days, a thick layer of corrosion products combined with steel oxides was observed (Figure 11(e)).

3.6. Average Corrosion Rate. Average corrosion rates (Figure 12) were calculated from the weight losses of the samples. In soils without SRB, 0.5 wt% carbamide remarkably inhibited soil corrosion, while in soil with SRB, the addition of carbamide also decreased average corrosion rate of Q235 steel but the reason is different from the previous case. Besides, corrosion rate in soil with SRB was much larger than that in soils without SRB, which further proved that SRB accelerated soil corrosion. The effect of water content in soil on corrosion rate was also shown. In soil without SRB, corrosion rate was lower in moisture of 30%, as the saturated water content allowed even less dissolved oxygen and then prevented cathodic polarization, with corrosion rate down. In soil with SRB, corrosion rate was also smaller in moisture of 30% because SRB are able to survive or even take advantage of the presence of molecule oxygen [32]. The surface morphologies are shown in Figures 13 and 14. To check this effect, different concentrations of carbamide were added in soil with and without SRB and weight-loss tests were done to measure the corrosion rate. The results (Figure 15) show that in soil without SRB carbamide inhibits corrosion and the inhibition effect increases with increasing carbamide concentration. In soils with SRB, 10% humidity promotes the corrosion; the effect increases with the increase of the carbamide concentration [23]. Meanwhile,

in soils with 20% moisture, carbamide promotes corrosion but the effect decreased with the carbamide concentration increasing. With 0.5 wt% of carbamide, it inhibited biocorrosion of carbon steel. In soils with 30% moisture, the inhibition of corrosion increases with increasing carbamide concentration. Hence, carbamide can be used as an effect inhibitor in soils for both common corrosion and biocorrosion.

4. Conclusions

Carbamide decreased soil redox potential, and so did SRB. Some carbamide was decomposed into CO_2 and NH_3 , which increased the pH value. SRB decreased soil pH due to its metabolic products. But the effect of carbamide took a bigger part. In soil without SRB, carbamide induced the corrosion potential of Q235 steel which was much more positive and inhibited its corrosion. In inoculated soil, excessive carbamide restrained the growth of SRB and inhibited biocorrosion of Q235 steel. In different water content, there was less oxygen in soil with the moisture of 30%, so corrosion rate declined in both soils with and without SRB. Carbamide can be a potential inhibitor for soil corrosion and biocorrosion.

Data Availability

The authors claim that all the underlying data in this manuscript is fully available and publishable without restriction.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

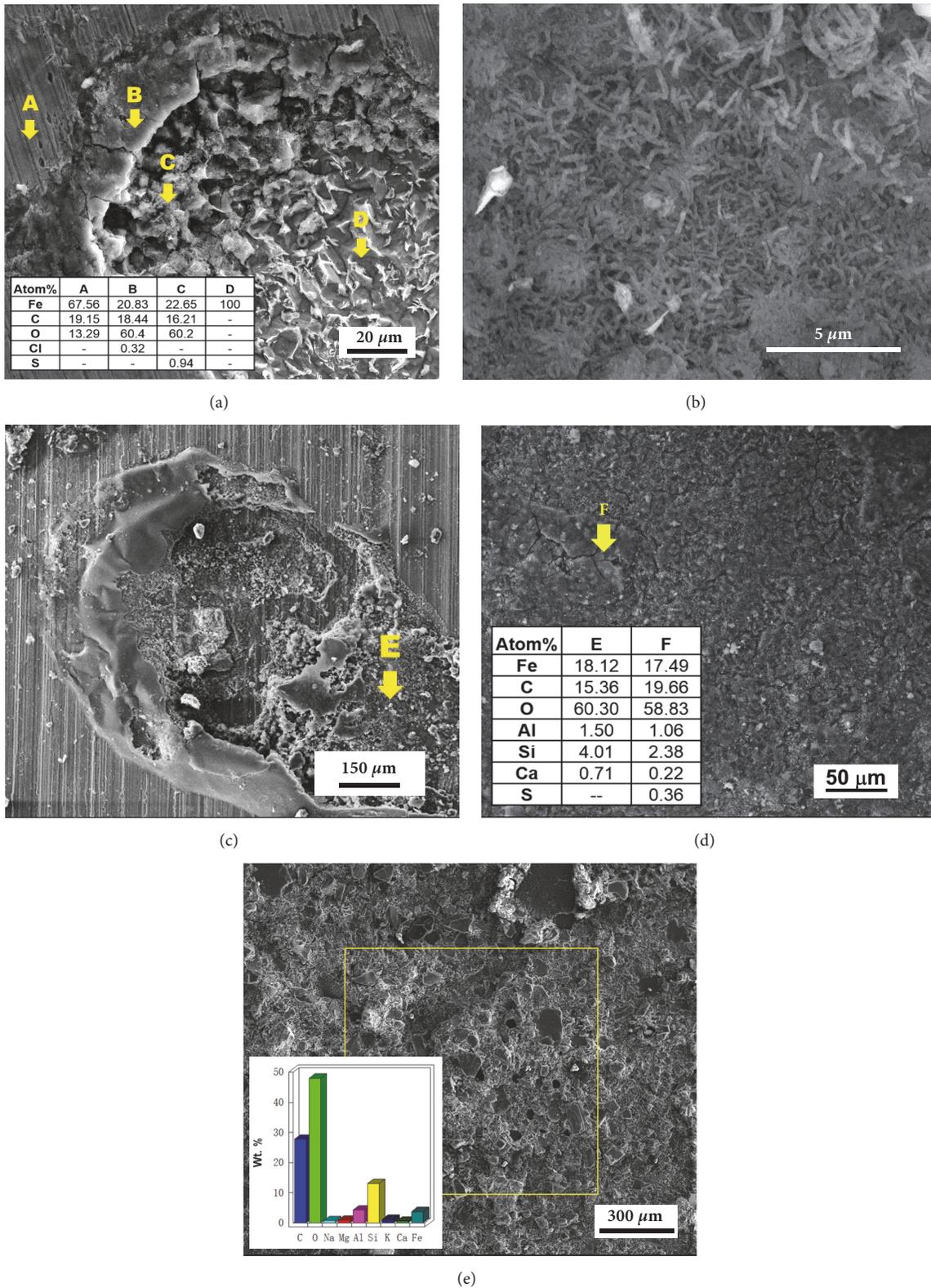


FIGURE 11: SEM and EDS data of specimen in soils with moisture of 20 wt%: (a and b) 0 wt% carbamide+SRB @15 days; (c and d) 0 wt% carbamide+SRB @ 65 days; (e) 0.5 wt% carbamide+SRB @ 65 days.

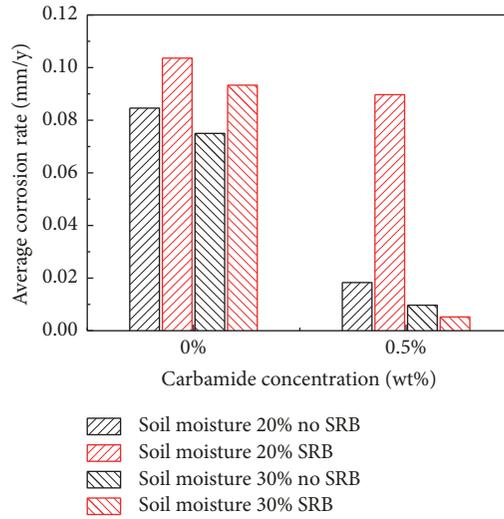


FIGURE 12: Average corrosion rate (mm/y) of Q235 steel in soil after 65 days.

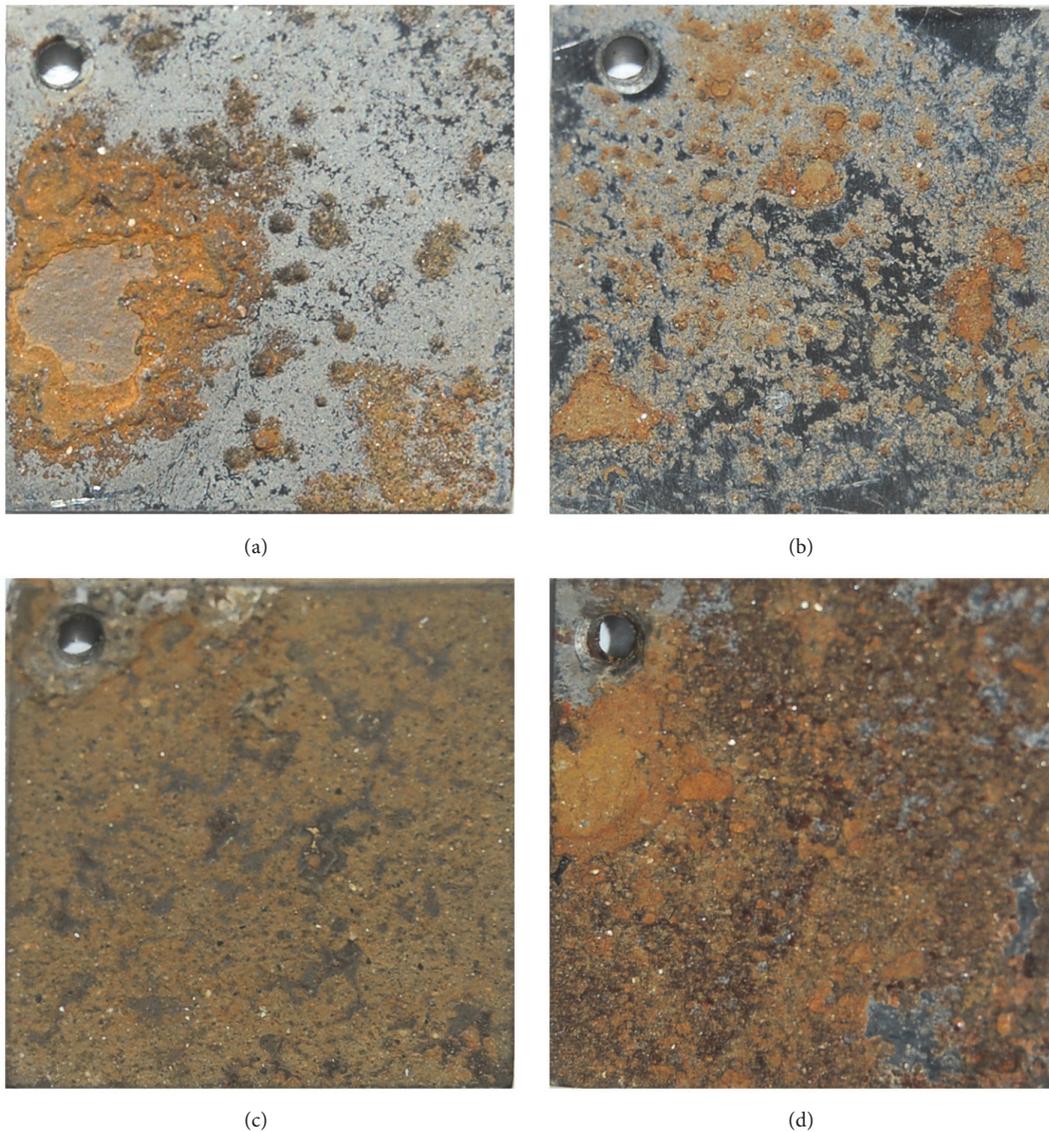


FIGURE 13: Surface morphologies of specimen in soils with moisture of 20% after 65 days. (a) 0% carbamide, (b) 0.5% carbamide, (c) 0% carbamide+SRB, and (d) 0.5% carbamide+SRB.

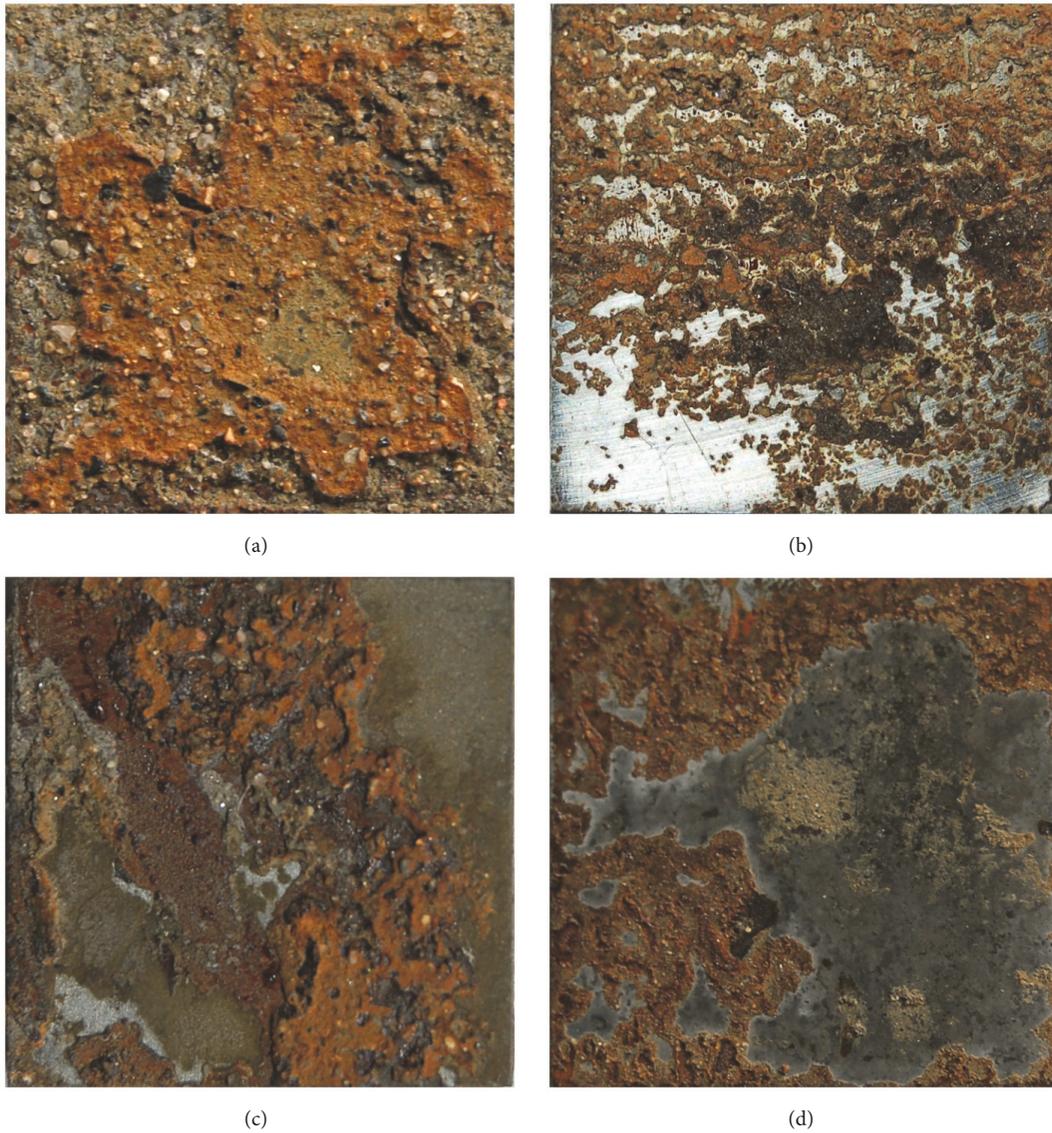


FIGURE 14: Surface morphologies of specimen in soils with moisture of 30% after 65 days. (a) 0% carbamide, (b) 0.5% carbamide, (c) 0% carbamide+SRB, and (d) 0.5% carbamide+SRB.

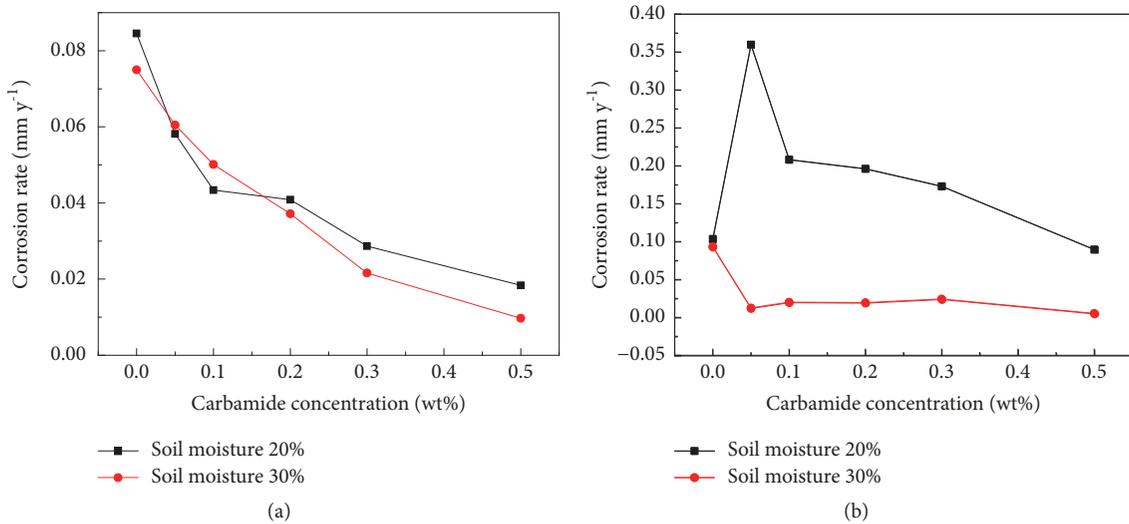


FIGURE 15: Average corrosion rate of carbon steel in soil without SRB (a) and with SRB (b) with carbamide concentration.

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