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Short Communication

Influence of alternating current on corrosion behavior of X100 steel in Golmud soil simulated solution with different pH

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The alternating current (AC) corrosion behavior of X100 steel was studied in Golmud soil simulated solution with different pH using electrochemical measurement, immersion test and surface analysis technology. The results show that AC interference and pH can collectively affect the corrosion behavior of the steel. The applied AC weakens the oxygen depolarization, enhances the hydrogen evolution reaction, and promotes the corrosion of the steel. The corrosion form of the steel evolves from non-uniform general corrosion to localized corrosion as i_{AC} increases. Under the same interference of i_{AC}, the corrosion rate of the steel first decreases and then increases with increasing the pH value. The difference in the characteristics of corrosion products can affect the corrosion resistance of the steel to a certain extent. When AC is applied, a great number of cracks existing in the corrosion products of sample under the condition of pH=7 result in the severe corrosion. In contrast, the compactness corrosion product is conducive to protect the steel substrate tested at pH of 9.

Keywords: Corrosion behavior; AC interference; X100; pH

1. INTRODUCTION

Currently, increasing corrosion failure cases of buried pipelines are closely related with the alternating current (AC) interference[1-2]. A great number of laboratory studies have indicated that the superimposed AC promotes the corrosion of pipeline steels[3-5]. Jiang[6]reported that tafel slope determined the change trend of offset direction of corrosion potential. Tang [7] have concluded that AC interference affects the cathodic current provided by magnesium and causes the reduce in protection effect for pipeline steel. Wan [8] found that Bacillus cereus accelerated the formation of pits, and enhanced the SCC susceptibility. Wang [9] indicated that the susceptibility to SCC of pipeline steel under CP condition was promoted due to the imposed AC. Our recent studies [10-12] reported that AC application induced the change in SCC mechanism, and AC corrosion behavior of pipeline steel was closely related with the phase composition and its content within the microstructure. Additionally, the metallurgical structure and the formed passive film impacted the AC corrosion behavior of pipeline steel tested in carbonate/bicarbonate solution[13].

Various theories[14-15] on the AC corrosion mechanism have been proposed. Yunovich [16] pointed out that the corrosion degree of steel was improved by the applied AC, which was attributed to the generation of a net oxidation current. Bertocci [17] investigated the influence of the proportion of anodic and cathodic Tafel slopes on the AC corrosion behavior. Our previous study[18] reported that AC generated a harmful impact on the compactness and protection ability of passive film formed on the surface of pipeline steel. Yet, the AC corrosion behavior and mechanism should be further studied due to the controversial acknowledge.

In future, X100 steel may be widely adopted as the pipeline material due to its excellent comprehensive properties. In northwestern China, long-distance pipelines pass through the Golmud soil. The difference in the pH value of the salty soil exists. As the important corrosion factor, the combination effect of pH value and imposed AC may facilitate the corrosion of pipeline steel. At present, no literature on the effect of pH value on AC corrosion behavior of X100 pipeline steel has been reported. Thus, it is meaningful to investigate this topic.

In this work, the corrosion behavior of X100 steel interfered by AC is investigated in Golmud soil simulated solution with different pH by electrochemical measurement, immersion test and surface analysis technology.

2. EXPERIMENTAL

2.1. Material and solution

The test specimens were cut from an X100 pipeline steel sheet. The chemical composition of the steel was as follows (wt.%): C 0.04, Si 0.20, Mn 1.50, P 0.011, S 0.003, Mo 0.02, and Fe balance.

Before the experiment, the steel electrodes were grinded sequentially with SiC sandpapers from 320# to 2000#, followed by rinsing with deionized water and finally dried with ethanol. According to the main physical and chemical data of Golmud soil, the component of a simulated solution was[19]: 11.34% Cl^-, 0.262% SO_4^{2-}, 0.0099% HCO_3^-. The experimental solution was equilibrated with analytically pure grade of NaCl, Na_2SO_4, $NaHCO_3$ and deionized water. Then, the solutions were matched by using 5% NaOH solution to adjust the pH value to7,9 and 11, respectively. All tests were performed at ambient temperature of about 25°C, and the solutions were not deaerated.

2.2. Electrochemical measurements

The test was conducted at PARSTAT 2273 electrochemical workstation with a conventional three-electrodes system, where a large sheet of Pt was acted as the counter electrode, a saturated calomel electrode (SCE) served as the reference electrode, and the steel used as the working electrode.

The testing device of AC interference corrosion was in keeping with our previous research[10].The potentiodynamic polarization curve was measured at a potential range of -1 V (vs. SCE) to -0.3 V (vs. SCE) with a scanning rate of 1mV/s. During the testing process, 50 Hz sine wave with different current densities of 0, 30 and 50 A/m ^{2} was applied to the steel sample.

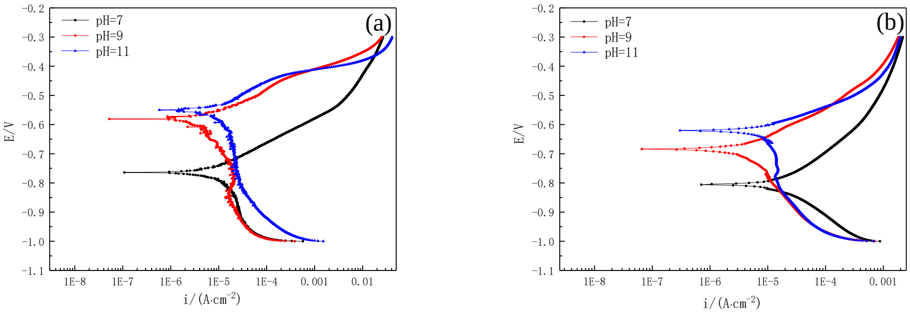
2.3 Immersion test

In this test, the imposed AC circuit in the above testing device was adopted. Prior to testing, the steel specimen was weighed. Then, the test was performed at different current densities (0, 30 and 50 A/m ^{2}) in Golmud soil simulated solution with various pH (7, 9 and 11) for 120h. At the end of the test, the corrosion morphologies of samples applied at different current densities were observed by SEM. Subsequently, the corroded samples were cleaned by a rust removing solution, followed by drying and weighing. According to the weight loss, the corrosion rate of the steel interfered by AC was calculated.

3. RESULTS

3.1. Electrochemical measurement

Figure 1 displays the potentiodynamic polarization curves of X100 steel measured at various AC current densities in the simulated solution with different pH. Without the imposed AC, the reaction of oxygen depolarization mainly occurs at the cathode portion of the curve. With the increase of AC current density, the oxygen depolarization gradually weakens, whereas the hydrogen evolution reaction is enhanced, especially at the pH of 7. The fitted corrosion current density (i_{corr}) of X100 steel samples under different AC current densities in the simulated solution with different pH was depicted in Figure 2. Obviously, the i_{corr} of the X100 steel increases under the condition of different pH as AC current density increases. Among them, under the same AC interference, the i_{corr} of the steel tested at pH of 7 is the maximum, followed by pH of 11, and that of pH of 9 is the lowest. Thus, AC current and pH can collectively affect the corrosion rate of the steel.



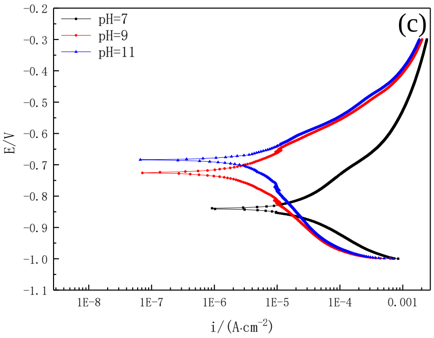


Figure 1. Polarization curves of X100 steel samples tested at different AC current densities in the simulated solution with different pH (a)without AC;(b)30 A·m^{-2};(c)50 A·m^{-2}

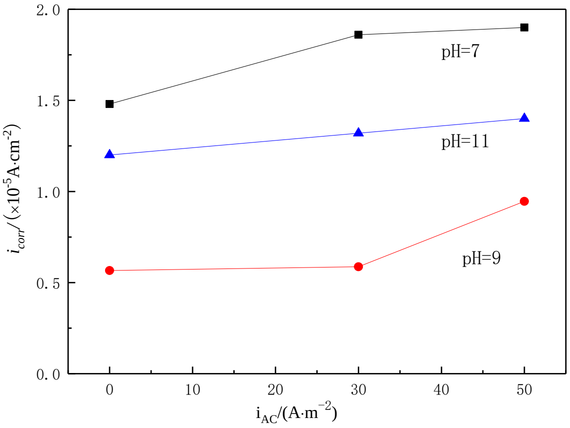


Figure 2. i_{corr} of X100 steel tested at different i_{AC} in the simulated solution with different pH

3.2. Analysis of corrosion morphology and corrosion product

Figure 3 exhibits the macro-corrosion morphologies of X100 steel tested at i_{AC} of 30 A/m^2 in the simulated solution with different pH. When the pH value of the simulated solution is 7, the corrosion product formed on the surface of the steel is incomplete and discontinuous. Some part of corrosion products fall off, indicating that the loose characteristics is not conducive to protect the steel substrate. With increasing pH value of the solution, the compactness and completeness is significantly better than that of pH of 7. Hence, the feature of corrosion products can effectively improve the protection ability. As shown in Fig.3c, However, some cracks existing inside the corrosion products would reduce its protection ability. Hence, the difference in the characteristics of corrosion products can affect the corrosion resistance of the steel to a certain extent.

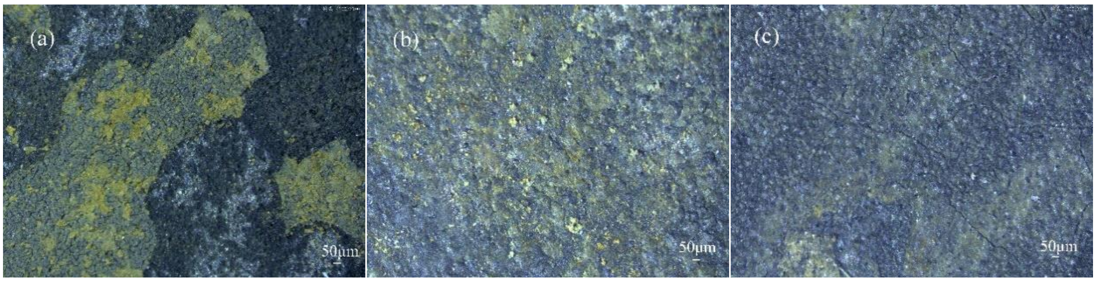
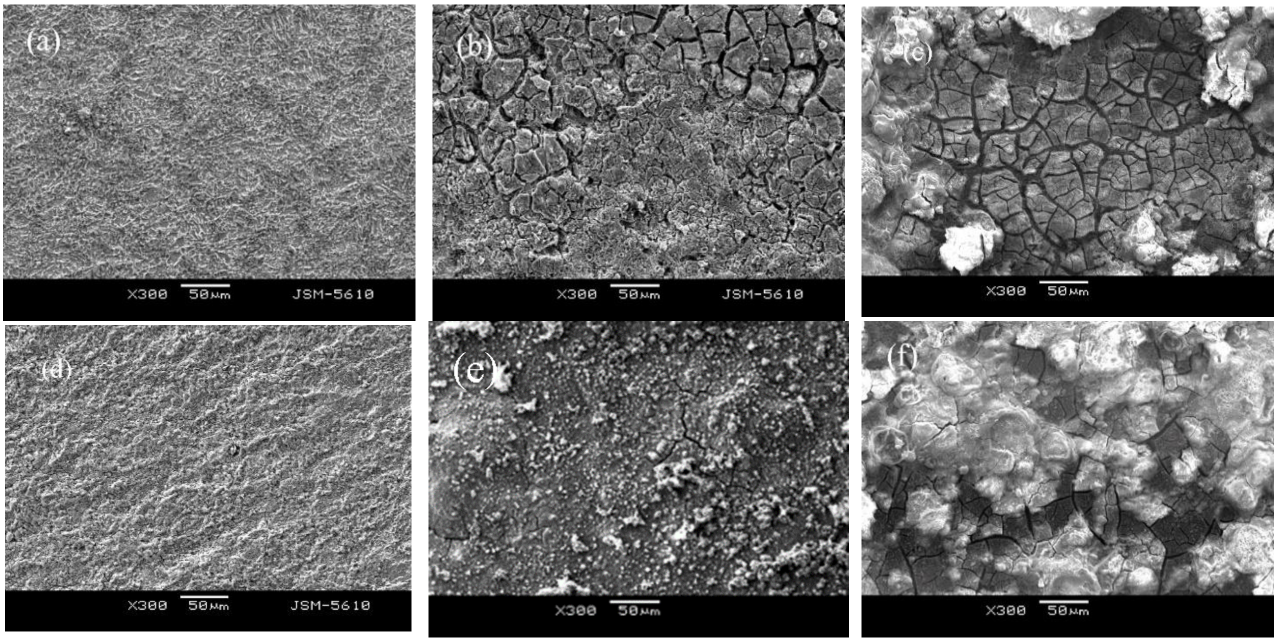


Figure 3. The macro-corrosion morphologies of X100 steel tested at i_{AC} of 30 A/m^2 in the simulated solution with different pH (a) pH=7;(b) pH=9; (c) pH=11

Figure 4 shows the micro-corrosion morphologies of X100 steel at various AC current densities in Golmud soil simulated solution with different pH. Fig.4a, d and g exhibit that the corrosion morphologies of the samples without the applied AC is similar, with a small amount of corrosion products. Obviously, when AC is imposed, a large amount of corrosion products formed on the surface of samples indicates that the applied AC promotes the corrosion of the steel. Fig.4b and c display a great number of cracks existing in the corrosion products of sample under the condition of pH=7. These defects provide that channels that make the reactants easily reach the substrate interface, causing the occurrence of severe corrosion. Clearly, at pH of 9, the compactness and completeness of corrosion products is significantly improved, with few cracks. As pH value increases up to 11, some large and small sized cracks are distributed in the corrosion products.



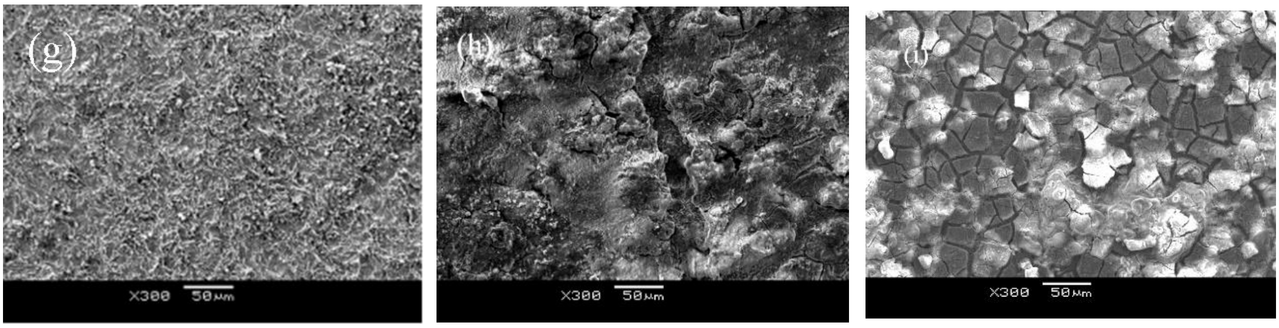


Figure 4. Micro-corrosion morphologies of X100 steel tested at different AC current densities in simulated solution with different pH (a) pH=7; (b) pH=7, i_{AC}=30A/m^2; (c) pH=7, i_{AC} =50A/m^2;(d) pH=9; (e) pH=9, i_{AC} =30A/m^2; (f) pH=9, i_{AC} =50A/m^2; (g) pH=11; (h) pH=11, i_{AC} =30A/m^2;(i) pH=11, i_{AC} =50A/m^2.

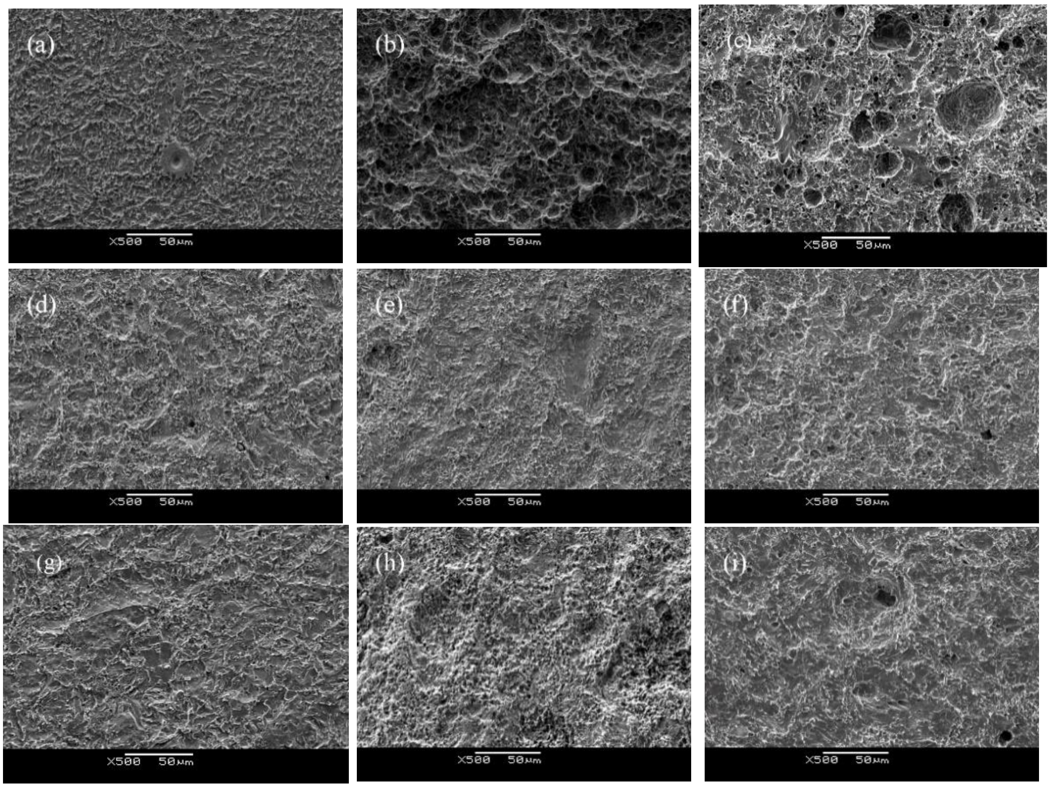


Figure 5. Micro-corrosion morphologies of corroded X100 steel after the removal of corrosion products (a) pH=7; (b) pH=7, i_{AC} =30A/m^2; (c) pH=7, i_{AC} =50A/m^2;(d) pH=9; (e) pH=9, i_{AC} =30A/m^2; (f) pH=9, i_{AC} =50A/m^2;(g) pH=11; (h) pH=11, i_{AC} =30A/m^2; (i) pH=11, i_{AC} =50A/m^2.

Figure 5 shows the micro-corrosion morphologies of corroded X100 steel after the removal of corrosion products. The similar feature of non-uniform general corrosion is revealed for the samples without AC application (Fig.5a, d and g). As shown in Fig. 5b and c, the specimens under imposed AC exhibit the serious corrosion degree, with a large number of different sized pits. And these small pits dissolve and form the large and deep pits. The characteristics indicate that localized corrosion is the major corrosion form. In contrast, when pH value increases to 9 and 11, the relatively slight corrosion status is displayed, with a small number of shallow pits. Thus, the applied AC promotes the corrosion of the steel. Under the same condition, the steel sample measured at pH of 7 possesses the severe corrosion status, followed by the pH of 11.

3.3 Corrosion rate

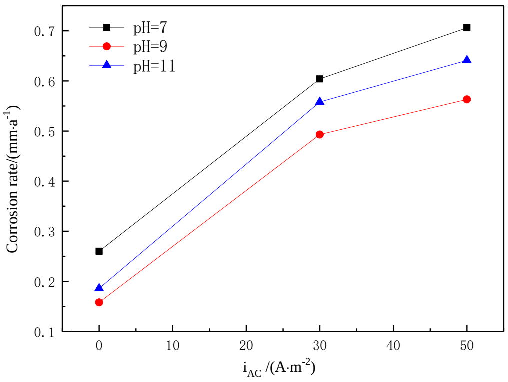


Figure 6. Corrosion rate of X100 steel tested at various i_{AC} in simulated solution with different pH

As revealed in Figure 6, at different pH, the applied AC apparently facilitates the corrosion of the steel, i.e., the corrosion rate increases as the i_{AC} increases. Under the same interference of i_{AC}, the corrosion rate of the steel first decreases and then increases with the increase of pH value. That is, the steel tested at pH of 7 has the maximum corrosion rate, followed by pH of 11, and the steel sample measured at pH of 9 possesses the minimum corrosion rate. The result is in line with that of polarization curve.

According to the above testing results, the applied AC weakens the oxygen depolarization, and enhances the hydrogen evolution reaction. This is attributed to that imposed AC increases the electric field intensity inside in the solution[20], promotes the diffusion rate of ions (H^+, et al), causing an promotion in hydrogen evolution reaction[21]. Our previous research [10]indicated that hydrogen evolution reaction became more easily as AC current density increases. Moreover, the pH of 7 is beneficial to the occurrence of hydrogen evolution reaction. It is unanimously known that the presence of H can facilitate the formation of pits[22]. Yang [23] reported that H atoms enriched in voids and inclusions, resulting in the occurrence of pits due to hydrogen induced anodic dissolution. Hence, AC improves the corrosion rate of X100 steel.

Furthermore, as shown in Fig. 4, the corrosion products of steel samples tested at imposed AC contain a great amount of cracks, especially for the pH values of 7 and 11. Thus, the corrosive ions in the solution easily infiltrate the defects into the local micro-area of matrix interface, causing the formation of occluded corrosion cell (OCC) and the occurrence of corrosion pits.

In addition, the soil solution with pH of 11 due to the excess OH^- could decrease the spread resistance[24], and facilitate the corrosion of the steel. Based on the above statement, when pH is 9, the steel exhibits the optimal corrosion resistance. Thus, AC interference and pH can collectively affect the corrosion behavior of the steel.

4. CONCLUSIONS

AC interference and pH can collectively affect the corrosion behavior of the steel. The applied AC weakens the oxygen depolarization, enhances the hydrogen evolution reaction, and promotes the corrosion of the steel. The corrosion form of the steel evolves from non-uniform general corrosion to localized corrosion as i_{AC} increases. Under the same interference of i_{AC}, the corrosion rate of the steel first decreases and then increases with increasing pH value. The difference in the characteristics of corrosion products can affect the corrosion resistance of the steel to a certain extent. When AC is applied, a great number of cracks existing in the corrosion products of sample under the condition of pH=7 result in the severe corrosion. In contrast, the compactness corrosion product is conducive to protect the steel substrate tested at pH of 9.

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