Corrosion behavior of the weld joint of X80 pipeline steel in an acidic red soil

Xianming Cao, Tangqing Wu, Meng Liu, Binbin Wang, Minghua Zhang, Cong Li and Fucheng Yin

Abstract

In this paper, the corrosion behavior of X80 pipeline steel weld joints in an acidic red soil solution was studied. The results show that uniform corrosion occurs on the entire surface of the weld joint after 840 h immersion. The corrosion degree of heat affected zone (HAZ) is more serious than that of base metal (BM) and weld zone (WZ). The corrosion rate of HAZ specimen is always higher than those of WZ and BM specimens throughout the separated immersion. The accelerating corrosion of HAZ may come from its microstructure change, its corrosion sensitivity and the deterioration of mechanical performance of corrosion product on it.

1. Introduction

Corrosion is the performance degradation phenomenon of metals under the action of the surrounding medium [1, 2]. The annual economic loss caused by corrosion accounts for 3%~5% of the world’s GDP, and 20% of the total corrosion are related to soil corrosion [3–5]. According to Pipeline and Hazardous Materials Safety Administration (PHMSA), about 300 major accidents were annually took place in United States, causing $310 million or more in direct damage (https://phmsa.dot.gov/). In their survey corrosion brings about 18.0% of pipeline accidents, while the Canadian National Energy Board believes the figure could be as high as 62.3% (https://cer-rec.gc.ca). The above surveys show that corrosion failure is a serious threat to the safe operation of oil and gas pipelines buried in soil environments [6–8].

Welding is widely used in the connection of oil/gas pipelines [9, 10]. Corrosion failure is more likely to generate in weld joint, on account of its drastic changes of ingredient, microstructure and property [11–16]. And many researches on corrosion behavior and mechanism of weld joint of pipeline steel have been carried out in laboratory by domestic and foreign scholars [17–21]. Kato et al. explored the corrosion behavior of weld joints of carbon steel in a seawater and found that MnS inclusion, which formed during weld process, could improve the local corrosion sensitivity of weld tissues. A macro-corrosion galvanic cell is established between the weld zone and the base metal, which causes groove corrosion of the carbon steel weld joints [22]. Luo et al. have confirmed via scanning reference electrode technique (SRET) and scanning vibrating electrode technique (SVET) experiments, that in both the NaCl and NS4 solutions the corrosion potential of weld zone (ferritin tissue) of carbon steel is more negative and its anode current density is higher than these of the base zone (organization of ferrite and pearlite), respectively. The facts indicate the exist of the galvanic current between the weld zone and base zone, which brings out the preferential dissolution of the weld zone and hence the V-shaped groove corrosion [23]. Zhang et al. have studied the electrochemical corrosion behavior of X70 steel weld joints in bicarbonate/carbonate solutions and found that the passivation current density in the heat affected zone is higher than that in the weld area and the base metal, while its concentration of electron receptor is higher and its space electron transfer layer is thinner than these in latter two [24]. In conclusion, the local corrosion induced by
MnS impurities and the galvanic current corrosion between different zones in weld joint have been recognized as the main reasons for the corrosion of weld joints. China’s west-east gas transmission project has extended to South China. The main type in the zone is acidic red soil and its pH of acid red soil is mainly lower than 5.0 [25–27]. The corrosion rate of pipeline steel is accelerated and its corrosion mode tends to anodic dissolution, which is rightly different from the corrosion in marine and near-neutral pH environments [28]. However, the corrosion behavior of weld joints of pipeline steel in acidic red soil has not been ignorant. In this paper, the corrosion behavior of weld joints of X80 pipeline steel in an acidic red soil solution was studied by optical microscope, electrochemical measurement, SEM/EDS and 3D ultra-depth microscopy. The differences in corrosion behaviors among base zone, heat affected zone and weld zone were compared and the corrosion mechanism of weld joints in acidic environment is discussed. The results are beneficial for the corrosion protection of weld joints in acidic soil environment.

2. Material and methods

2.1. Specimen

The pipeline steel used in the experiment was an API X80 steel pipe produced by Baoshan Iron & Steel Co., Ltd, with the thickness of 21 mm and the diameter of 1422 mm. Its chemical composition is shown in table 1. The steel was weld via GMAW-P girth weld with the BOEHLER SG8-P solid weld wire. The protective gas is the mixture of Ar (80 vol%) and CO₂ (20 vol%). The detailed weld processes are same as these [29].

The specimens (20 mm × 30 mm × 5 mm) containing weld zone (WZ), heating affected zone (HAZ) and base metal (BM) were machined from the weld joint. Then the specimens were abraded with a series of grit papers (280#, 600# and 1000#), polished with a polishing agent (1.5 μm), cleaned with deionized water and ethanol, and dried by cold air. These specimens were named as weld joint specimens (WJS) in this paper. At the same time, some WJS were etched with the mixture of nitric acid (4 vol%) and alcohol (96 vol%), to show the three zones (WZ, HAZ and BM) in WJS (figure 1). Then WJS were machined as shown in figure 1, obtaining the specimens solely containing one of the three zones, and these specimens were named as WZ, HAZ and BM, respectively. The specimens were polished and etched as the above processes, and their microstructures were observed by OLYMPUS-PME3 metallographic microscope. The Vickers hardness of the weld joint was conducted by HM-5L Vickers Hardness Tester with the applied load of 200 gf and the loading duration of 15 s. A copper wires was welded on the back of each specimen, and its non-working surfaces were sealed with epoxy resins.

| Table 1. Chemical compositions of X80 pipeline steel (wt%). |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| C   | Si  | Mn  | P   | S   | Ni  | Cr  | Cu  |
| 0.0466 | 0.204 | 1.754 | 0.0082 | 0.0009 | 0.206 | 0.235 | 0.174 |
| Nb  | V   | Ti  | Mo  | Al  | B   | Fe  | P_{cm} |
| 0.0524 | 0.0022 | 0.0142 | 0.125 | 0.0265 | 0.0004 | Balance | 0.1753 |

Figure 1. Machining position of base metal (BM), heat affected zone (HAZ) and weld zone (WZ) from weld joint.
working surface was abraded, polished, cleaned and dried in sequence with the same processes above, to conduct electrochemical measurements. It must be noted here that, the HAZ specimen contains all three zones as shown in figure 1, thus prior to experiment its working surface was sealed with via silica gel only leaving heating affected zone for electrochemical measurements. The HAZ area for each HAZ specimen was obtained by digital camera and ScanIt software.

2.2. Immersion experiment
The soil used in the experiment was collected from 1.5 m below ground at Xiangtan, Hunan Province (27.8811° N, 112.0936° E). The soil is an acid red soil of South China, without gravel and foreign matter. Exposed in sunshine for three days, the soils were pulverized by a multi-purpose grinder, ground with a 1 mm fine sieve, and dried in oven (70 °C) for three days. After that, the dried soil and deionized water (1:1, mass ratio) were mixed mechanically and stood for 5 days. The supernatant liquid of the mixture was repeatedly filtered with filter papers until to getting the clarified soil solution. The soil solution was stored at 4 °C for use.

Prior to experiment, a liter of the soil solution was transferred into a jar and high-purity nitrogen gas was filled in it for 2 h to remove oxygen in the soil solution, making the dissolved oxygen content to be less than 0.3 mg l−1. The weld joint specimen (WJS) and the specimens solely containing one of the three zones (WZ, HAZ and BM) were immersed together in containing the soil solution. Then, the jar was completely sealed with silica gel, and the solutions in the jar were filled again with high-purity nitrogen for two hours to ensure an oxygen-free environment. The experiment was conducted at room temperature (25 ± 2°C) and rightly lasted for 840 h. Some electrochemical measurements were performed at intervals during the immersion, while the morphology and component analysis were conducted after the immersion.

2.3. Electrochemical measurement
Electrochemical measurements were conducted by CS350 electrochemical measurement system with a three-electrode electrochemical cell [30, 31]. A saturated calomel electrode (SCE) and a platinum electrode were used as the reference electrode (RE) and the counter electrode (CE), respectively. All potentials in the work were reported versus to SCE.

Electrochemical impedance spectroscopy (EIS) measurements were performed at intervals for the specimens solely containing one of the three zones (WZ, HAZ and BM). The amplitude of the applied sinusoidal signal is 5 mV and the frequency of the sinusoidal signal ranges from 10⁵ to 5 × 10⁻³ Hz. The measured electrochemical results were numerically fitted by ZSimpwin software. The Tafel polarization curves within a range of −250 mV to +250 mV (versus OCP) were tested at a scan rate of 1 mV s⁻¹ after immersion for 840 h. The test results were fitted by Origin 8.0 software.

2.4. Micro-topography observation and elemental analysis
After the immersion experiment, the specimens were washed repeatedly with absolute ethanol and dried quickly via pure N₂, to be used for micro-topography observation and elemental analysis. A scanning electron microscope (SEM, Zeiss EVO MA10 or JEOL JSM-6360LV) with energy disperse spectroscopy (EDS, OXFORD X-Max® or INCA 250) was used to observe to micro-topography and detect the elemental composition of the corrosion product on the specimen surfaces. After that, the surface corrosion products were completely removed using a mixture of 500 ml HCl, 500 ml H₂O and 3.5 g hexamethylenetetramine and the corrosion morphology of the specimens were detected via SEM. The 3D images of the specimen surfaces were reconstructed via 3D ultra-depth microscopy (VHX-2000).

3. Results

3.1. Soil and soil solution analysis
The morphology and XRD pattern of the red soil after grinding and sieving are presented in figure 2. The red soil appears red brown and is shaped as small particles with diameters from 3 μm to 30 μm. EDS results show that its main ingredient contains are O, Si, Al and Fe, and XRD results confirm the exist of SiO₂, Al₂O₃ and FeO. After repeatedly filtered, the corresponding soil solution is extremely limpid as shown in inlet of the figure 2(a). The chemical parameters of the soil solution are listed in table 2. In the table, only pH and the concentrations of the key ions relevant to corrosion process are detected, pH and electrical conductivity of the soil are 5.74 and 64.1 μs cm⁻¹, respectively. Its concentrations of Cl⁻ and SO₄²⁻ are 4.29 and 9.51 mg l⁻¹, respectively.

3.2. Microstructure and hardness of the weld joint
The microstructures of the different zones in the weld joint are shown in figure 3. The microstructure in the base metal (BM) is mainly composed of quasi-polygonal ferrite, with uniform M/A islands distributing in it. A small
Figure 2. Macro-morphology (a), micro-morphology (b) and XRD pattern of the red soil, and the macro-morphology of the soil solution (inlet of the figure 2(a)).

Table 2. Chemical parameters of the soil solution.

| Soil type      | pH  | $K_{\text{iss}}$ cm$^{-1}$ | Cl$^-$/mg l$^{-1}$ | SO$_4^{2-}$/mg l$^{-1}$ | Salt content/mg l$^{-1}$ |
|----------------|-----|---------------------------|---------------------|-------------------------|--------------------------|
| Acid red soil  | 5.74| 64.1                      | 4.29                | 9.51                    | 80.1                     |
amount of polygonal ferrite also can be observed in the microstructure. A large amount of martensite and a little bainite are included in the heat-affected zone (HAZ), and M/A islands inlay in them. The grains are coarse and uneven, and their dislocation density is high. The acicular ferrite and bainite in the weld zone (WZ) are cross-distributed with relatively high density of dislocation [32, 33]. The hardness distribution in the weld joint is presented in figure 4. The hardness of WZ is slightly higher than that of BM, but higher than that of HAZ. The average hardness (224.57 HV) of BM, HAZ and WZ are 224.57, 265.35 and 239.91 HV, respectively. The highest hardness of HZA is relative to the new forming bainite.

3.3. Corrosion behavior of the weld joint in the soil solution

Figure 5 shows the corrosion products on the surface of X80 steel weld joint specimens (WJS) after 840 h immersion in the soil solution. A corrosion product film was completely covered on the WJS, and the corrosion product film cracked during the dehydration process after the immersion (figure 5(a)). However, the morphology and composition of corrosion product on WZ surface are significantly different from those on HAZ and BM surfaces. The corrosion products on WZ surface are the denser and lighter than those on HAZ and BM surfaces. The dehydration micro-cracks of the corrosion product are relatively narrow, which indicates that the corrosion products on WZ surface have better mechanical properties comparing with HAZ and BM surfaces (figures 5(b) and (c)). The color of the corrosion products on HAZ and BM surfaces is relatively dark.

Figure 3. Microstructures of the different zones in the weld joint: BM (a), (b); HAZ (c), (d); WZ (e), (f).
The corrosion products on HAZ surface severely crack during the dehydration process, and the cracks are wider than those on the WZ and BM surfaces (figures 5(d) ∼ (g)), which indicates that the mechanical properties of the corrosion products on HAZ surface are worst (figures 5(d) and (e)).

Corrosion morphologies of the joint surface after 840 h immersion in the soil solution are presented in figure 6. The corrosion morphologies in different zones on the WJS surface are relatively flat, without obvious pitting and local corrosion, indicating the uniform corrosion type for the WJS surface. However, as shown in the magnification images, the roughness of corrosion morphology on BM surface is the minimum (figures 6(e) and (f)), while that on HAZ is the maximum (figures 6(c) and (d)). In consideration of the characteristics of the corrosion products on WJS surface (figure 6), the higher roughness of the corrosion morphology on the HAZ may be related to the poor mechanical properties of its corrosion products. Besides, the corrosion morphology on HAZ surface is slightly similar to the HAZ microstructures in figure 3(d), thus it is reasonable to speculate that the corrosion morphology may be relevant to the microstructure changes during the aftercooling process of the weld procedure.

3.4. EIS result
Nyquist and Bode plots of WZ, HAZ and BM specimens during the separated immersion in the soil solution are shown in figure 7. At the initial stage of the experiment, the Nyquist plots of WZ, HAZ and BM specimens are all characterized by a compressed capacitive loop, and their radiiuses of these loops and the frequencies response in the Bode plots are similar (figures 7(a) and (b)), proving the similar corrosion behavior of the three zone at the initial stage. About 24 h later, the radiiuses of the impedance loops for WZ and BM specimens increase obviously, while that for HAZ specimen increases a little (figure 7(c)). After that, their radiiuses of the impedance loops decrease gradually, and decline by an order of magnitude on the 840th h (figure 7(i)), demonstrating the increase in corrosion rate for all specimens. By comparing the Nyquist plots for WZ, HAZ and BM specimens, it can be seen that the radiiuses of impedance loop of WZ specimen is always slightly larger than that of BM specimen, while it is significantly larger than that of HAZ specimen from the 8th h on. The facts verify that the corrosion rate of HAZ specimen in the soil solution is higher than those of WZ and BM specimens. All in all, the corrosion rates of the specimens firstly decline, then rapidly increase, and eventually remain stable. The zone in the weld joint with the highest corrosion rate in the soil solution is HAZ, and then BM and WZ successively.

3.5. Potentiodynamic polarization curves
Tafel polarization curves of WZ, HAZ and BM specimens after the 840 h separated immersion in the soil solution are presented in figure 8. It is obvious that the cathodic and anodic reactions on all the specimens are dominated by electro-chemical polarization. The fitted electrochemical parameters are listed in table 3. There is no significant difference in Tafel slope for the three different specimens, showing the similar anode process taking place on the weld joint surface. The corrosion current densities \(i_{corr}\) of WZ, HAZ and BM are \(2.174 \times 10^{-5}\), \(5.330 \times 10^{-5}\) and \(1.740 \times 10^{-5}\) A cm\(^{-2}\), and their corresponding polarization resistances \(R_p\) are 1267, 578.4 and 1606 Ω cm\(^{-2}\), respectively. The highest \(i_{corr}\) and the lowest \(R_p\) simultaneously appear at HAZ specimen, and the differences in \(i_{corr}\) and \(R_p\) between WZ and BM are
limited. The above results indicate that the corrosion processes of WZ, HAZ and BM specimens in the acid red soil are the same in the late stage of the experiment, while the corrosion rate of HAZ specimen is higher than that of the other two.

Figure 5. Micro-topography of the corrosion products on the surface of weld joint specimens (WJS) after 840 h immersion in the soil solution (a) and the enlargements in WZ (b), (c), HAZ (d), (e) and BM (f), (g).
3.6. Corrosion micro-morphology

Micro-topographies of the corrosion products on surfaces of WZ, HAZ and BM after 840 h separated immersion in the soil solution are presented in figure 9. The WZ specimen surface is covered with uniform and dense corrosion products, with obvious micro-cracks on it. These cracks may stem from the dehydration process and their width is relatively limited narrow (figures 9(a) and (b)). EDS results indicate that the main components of the corrosion products are Fe oxide and soil sediments (table 4). A uniform and complete corrosion product film is similarly covered on HAZ specimen surface, while the width of the cracks is much wider than that on the WZ specimen surface (figures 9(c) and (d)), which indicates that the mechanical performance of the corrosion product on WZ specimen surface is better than that on HAZ specimen surface. EDS results show that relatively high concentration oxygen and low concentration iron exist on the corrosion products on the HAZ specimen surface (table 4). The fact shows that the corrosion process was carried out more adequately on HAZ specimen surface, which is consistent with the results of EIS and polarization curves. The corrosion products on BM specimen surface are denser and more complete than those on WZ and HAZ specimen surfaces (figure 9(e)), and only some tiny and narrow micro-cracks exist on the surface (figure 9(e)).
The facts demonstrate that the corrosion products on BM specimen surface have good compactness and mechanical properties. EDS results show that the main components of the corrosion product are iron oxides and soil sediments (table 4).

Figure 7. Nyquist and Bode plots of WZ, HAZ and BM specimens during the separated immersion in the soil solution: 8 h (a), (b), 24 h (c), (d), 96 h (e), (f), 240 h (g), (h) and 840 h (i), (j).
Corrosion morphologies of WZ, HAZ and BM specimens after 840 h separated immersion in the soil solution are presented in figure 10. The main corrosion type of all the three specimens is uniform corrosion, with some shallow corrosion pits distributing on the surfaces. Compared with the WZ and BM specimens, the corrosion pits with deeper depths and wider widths can be easily observed on the HAZ specimen surface. The corrosion degree of HAZ specimen is higher than that of WZ and BM specimens. The results are in accord with the corrosion morphology of the weld joint specimens in the same soil solution (figure 6).

To quantify the differences in corrosion morphology between the three specimens, 3D morphologies of the corrosion attack surfaces of WZ, HAZ and BM specimens after the 840 h separated immersion in the soil solution were obtained by 3D ultra-depth microscopy, showing in figure 11. The maximum corrosion fluctuation in WZ, HAZ and BM specimens are 5.742, 7.550 and 1.387 μm, respectively, certifying the maximum corrosion degree taking place on HAZ specimen surface. The results are exactly consistent with the corrosion morphology obtained by SEM (figure 10).

### 4. Discussion

#### 4.1. EIS analysis for the WZ, HAZ and BM specimens in the acid soil solution

In EIS analysis, the impedance of the system at low frequencies (< 10 mHz) is related to the corrosion reaction taking place at the electrode/electrolyte interface, while that at high frequencies more than 10 kHz is relevant to the properties of the electrolyte in the rust defects and the bulk soil solution [34]. The capacitance in the region from 5 mHz to 10 kHz reflects the character of the double layer at the electrode/electrolyte interface covered under the rust defects. Besides, in EIS data the impedance at 10 mHz also contains the impedance at 10 kHz. Therefore, the impedance relevant to the corrosion reaction ($Z_p$) is calculated via subtracting the latter from the former. The equivalent circuit for corrosion process of the specimens is presented in figure 12, where $R_s$ is the impedance of the electrolyte and $Z_{NF}$ is the capacitance relevant to the double layer, respectively. Actually, the $Z_p$ from EIS is relevant to the $R_p$ from Tafel polarization curve in the same system at the actual time.

$Z_p$ of WZ, HAZ and BM specimens during the separated immersion in the soil solution are presented in figure 13. $Z_p$ of three specimens slightly increased at the initial stage, rapidly dropped from the 24 h on, and eventually remained stable. The $Z_p$ patterns for the three specimens are similar, indicating similar corrosion behavior on three specimen surfaces during the 840 h separated immersion in the soil solution. $Z_p$ of WZ and
BM specimens are almost the same throughout the immersion, while $Z_p$ of HAZ specimen is always lower than the former two, indicating that the corrosion rate of HAZ specimen is always higher than those of WZ and BM specimens in the acidic red soil solution. The polarization resistance $R_p$ of WZ, HAZ and BM specimens are also presented in Figure 13 via hollow symbols. After 840 h immersion, visible distinctions between $R_p$ and $Z_p$ can be seen from the figure, while the patterns of $R_p$ and $Z_p$ are similar with each other. The facts indicate indirectly that the electrochemical measurements (EIS and Tafel polarization curve) of the work are self-consistent.

Table 4. EDS results of the corrosion products on surfaces of WZ, HAZ and BM specimens.

| Position | O   | Fe  | C   | Si  | Mn  | K   | Cr  | Ni  | S   |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| A        | 35.70 | 38.86 | 14.78 | 5.63 | 0.81 | 0.45 | 0.44 | 2.67 | 0.66 |
| B        | 53.23 | 22.93 | 21.11 | 2.54 | /   | 0.88 | /   | /   | /   |
| C        | 42.46 | 36.94 | 8.92  | 9.73 | 1.25 | 0.70 | /   | /   | /   |

Figure 9. Micro-topographies of the corrosion products on surfaces of WZ (a), (b), HAZ (c), (d) and BM (e), (f) specimens after 840 h separated immersion in the soil solution.
4.2. Corrosion behavior of X80 pipeline weld joint in the acid soil solution

As shown in figure 6, uniform corrosion occurs on the entire surface of the weld joint during the 840 h immersion in the soil solution. The fluctuations of the corrosion morphologies of BM and WZ are limited, while it is relatively large for the heat affected zone. The corrosion products on WZ possess the densest structure and the best mechanical properties, however, the corrosion product on the heat affected zone tends to get cracking and form the wide micro-cracks (figure 5). It is reasonable to speculate that in the acid soil solution, the corrosion rates and morphologies of the three zones in the weld joint are significantly different. The corrosion rate in the heat affected zone is faster, its corrosion morphology is the most fluctuating, and the mechanical properties of the corrosion product on it are worse.

From the results above, at least three factors play important roles in accelerating the corrosion process of the heat affected zone in weld joint. The first factor is the relatively high corrosion sensitivity of the heat affected zone corresponding to previous investigations [17, 24, 35]. During the separated immersion, the HAZ specimen exhibits the high corrosion current density and the relatively serious corrosion attack, indicating the higher corrosion sensitivity of the HAZ specimen comparing to the WZ and BM specimens (table 3, figures 11 and 13). Obviously, its high corrosion sensitivity is relative to the heat affected zone in joint. The second factor is the microstructure change of the heat affected zone during the weld process [13, 36]. Metallographic results show

Figure 10. Corrosion morphology of WZ (a), (b), HAZ (c), (d) and BM (e), (f) specimens after 840 h separated immersion in the soil solution.
that the polygonal ferrite in the heat affected zone is larger and its boundary is more distinguishable than that in base metal, due to the aftercooling process in weld procedure (figure 3). Luo et al confirmed that ferrite in steel have relatively high corrosive activity and tend to corrosion preferentially [23]. Besides, the increase in grain size promotes. What’s more, the X80 pipeline steel in the work contains 1.80 wt% Mn, and the thermal shock in the weld process may promote the formation of MnS inclusions in heat affected zone. The MnS inclusion can improve the corrosion sensitivity of the weld structure [37, 38]. The third factor may be the poor mechanical

Figure 11. 3D morphologies of the corrosion attack surfaces of WZ (a), HAZ (b) and BM (c) specimens after the 840 h separated immersion in the soil solution.

Figure 12. Equivalent circuit for corrosion process of the specimens.
properties of the corrosion products on the heat affected zone. The corrosion products on the HAZ specimen surface and on the heat affected zone of the WJS specimen are severely cracked in the later dehydration process (figures 5 and 9). During the weld and subsequent cool process, the heat affected zone is subjected to a high thermal shock, and residual stresses may remain within it. In the immersion in soil solution, the residual stresses will release along with the corrosion process and convert into the growth internal stresses of the corrosion product. The growth stresses reduce the compactness and apparent mechanical properties of the corrosion products, affected the corrosion performance of the heat affected zone.

5. Conclusions

In this paper, the corrosion behavior of the three different zones of the weld joint in an acidic red soil is studied. The results are as follows:

1. After 840 h immersion in the soil solution, the corrosion products on the weld zone possess the densest structure and the best mechanical properties, however, the corrosion product on the heat affected zone tends to get cracking and form the wide micro-cracks.

2. Uniform corrosion occurs on the entire surface of the weld joint during the 840 h immersion in the soil solution. The fluctuations of the corrosion morphologies of base metal and weld zone are limited, while it is relatively large for the heat affected zone. The same phenomena took place on the WZ, HAZ and BM specimen surface separately immersed in the soil solution for 840 h.

3. The corrosion reaction for WZ, HAZ and BM specimens are dominated by electro-chemical polarization during the separated immersion in the acid soil solution. The corrosion rate of three specimens slightly decreased at the initial stage, rapidly increased from the 24th h on, and eventually remained stable until the end of the immersion. The corrosion rate of HAZ specimen is always higher than those of WZ and BM specimens throughout the separated immersion in the acid soil solution.

4. The accelerating corrosion of the heat affected zone in weld joint may come from its microstructure change, its corrosion sensitivity and the deterioration of mechanical performance of corrosion product on it.

Acknowledgments

We are grateful for financial support of National Natural Science Foundation of China (51971191, 51601164) and Hunan Provincial Natural Science Foundation of China (2019JJ30023, 2019RS2038).

ORCID iDs

Tangqing Wu https://orcid.org/0000-0002-0915-4554
Fucheng Yin https://orcid.org/0000-0003-2335-4437
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