

Study on the Crack Propagation Behavior of $\times 80$ Pipeline Steel Under AC Application in High pH Solution

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The crack propagation behavior of pipeline steels with or without AC application was studied in high pH solution using the crack propagation experiment (cyclic load). The results show that there is a significant difference in the crack propagation behavior of steels with or without AC interference. The crack growth rate (CGR) of steel under superimposed AC is considerably greater than that without AC. AC could cause an obvious effect on the crack propagation behavior, and enhance the CGR. The crack propagation behavior of steel under AC application in high pH solution is analogous to that in near-neutral pH solution.

Keywords AC application, crack propagation, high pH solution, pipeline steel

1. Introduction

With the rapid development of high-voltage AC power transmission lines, AC-powered rail transit systems and their sharing common right of way with the pipelines, AC corrosion is becoming the great threat to the safe operation of pipelines (Ref 1, 2). Fu (Ref 3) found that an applied AC could degrade passivity of carbon steel developed in carbonate/bicarbonate solutions. Xu (Ref 4) indicated that the corrosion of 16Mn pipeline steel was enhanced by the applied AC current density of 0–400 A/m². Kuang (Ref 5) thought that pitting corrosion could be initiated on the steel at sufficiently high AC current densities in both high pH and near-neutral pH solutions.

Our previous research (Ref 6) indicated that $\times 80$ pipeline steel under a long-term effect of AC interference exhibited a high SCC susceptibility in high pH solution and the crack propagation mode is transgranular. Moreover, the research result suggested that the crack propagation rate of the steel was enhanced due to AC application, compared to that in the absence of AC current (i.e. IGSCC fracture). At present, there is no related research about the crack propagation behavior of pipeline steel under AC application. In order to further quantify the crack growth rate (CGR) of the steel tested in the presence of AC, in this paper, the crack propagation behavior of $\times 80$ pipeline steel under applied AC was investigated in high pH solution using the crack propagation experiment.

2. Experimental

The compact tension (CT) specimen was cut from hot-rolled plate of API $\times 80$ pipeline steel. The chemical composition of

the steel is (wt.%): C 0.070, Si 0.216, Mn 1.80, P 0.0137, S 0.0009, Mo 0.182, Cr 0.266, Cu 0.221, Ni 0.168, Nb 0.105, Al 0.026, Ti 0.013, V 0.001, N 0.003 and Fe balance. The mechanical properties at room temperature were measured with tensile strength of 635 MPa and yield strength of 560 MPa. The specimen was made according to the procedures described in ASTM E647-08 (Fig. 1). In order to achieve an accurate measurement, the surface of the CT specimen was polished to 2000 grit finish prior to pre-fatigue cracking in air, and the crack length was measured using an optical microscope. In this paper, the classical solution system of high-pH SCC (0.5 mol/L Na₂CO₃ + 1 mol/L NaHCO₃) was used as the solution. The pH of the solution was 9.32.

The crack propagation experiment was conducted using a WDML-30KN Materials Test System. Cycle loads were applied to the CT specimen. Each cycle started from the maximum load (17,500 N) to the minimum load (10,000 N), and then the process was reversed. The initial corresponding ΔK value is 25.226 Mpa m^{0.5}. The test was performed at a frequency of 0.00125 Hz (800 s/cycle) for the entire process. The specimen was fixed in an organic glass container, and the container was kept airproof. The test was carried out using a three-electrode cell system, where the CT specimen was used as a working electrode, a platinum plate as a counter electrode, and a saturated calomel electrode (SCE) as a reference electrode. The specimen was maintained at a polarized potential of –580 mV (versus SCE). The potential applied to the specimen was in the middle of the potential range causing IGSCC (intergranular stress corrosion crack) (Ref 7). The sample was maintained at the potential by means of a PS-12 potentiostat.

In order to compare the crack propagation behavior of the steel without superimposed AC, a function generator of AT1645-3 model was used to provide the AC signal of 5 V. The AC sine wave with a frequency of 50 Hz was applied between the CT specimen and the platinum plate. The applied AC root mean square value of 10 mA in this work was measured using a clamp meter. During the whole process of the crack propagation test, the applied AC and DC currents were maintained at the initial condition. The experiment was performed at ambient temperature (~22 °C). After the test was completed, the corrosion product formed on the specimen was removed by a chemical method. By degreasing with

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acetone, followed by cleaning with deionized water, and finally drying in vacuum. The crack propagation morphologies were observed by stereo microscopy.

3. Results and Discussion

3.1 Microstructure Morphology

Figure 2 shows the microstructure of $\times 80$ pipeline steel. The microstructure of the steel is mainly composed of polygonal ferrite, acicular ferrite and a number of granular bainites distributed at grain boundaries.

3.2 Crack Propagation Analysis

Figure 3 shows the crack length of $\times 80$ steels with or without AC application versus number of cycles. As seen in

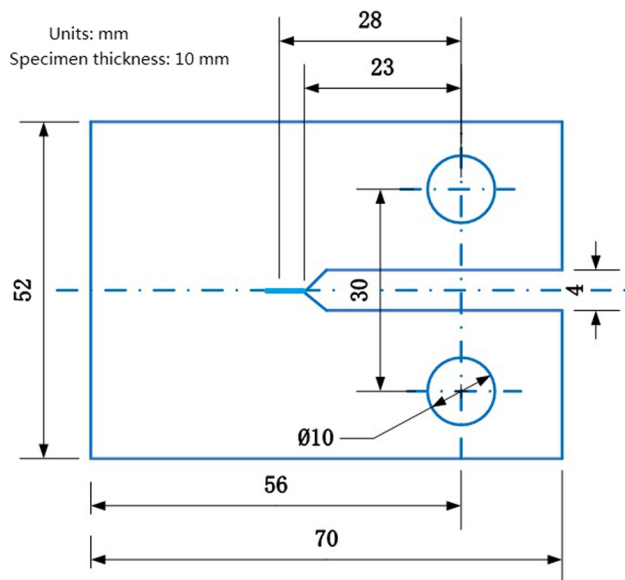


Fig. 1 The size of CT specimen

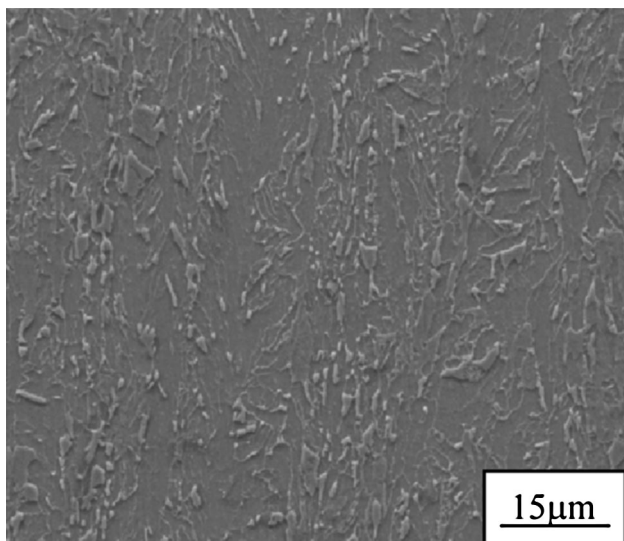


Fig. 2 The microstructure of $\times 80$ pipeline steel (Ref 8)

Fig. 3, a remarkable difference in the crack propagation behavior is found between the sample under superimposed AC and that without AC application. It is clearly seen that the

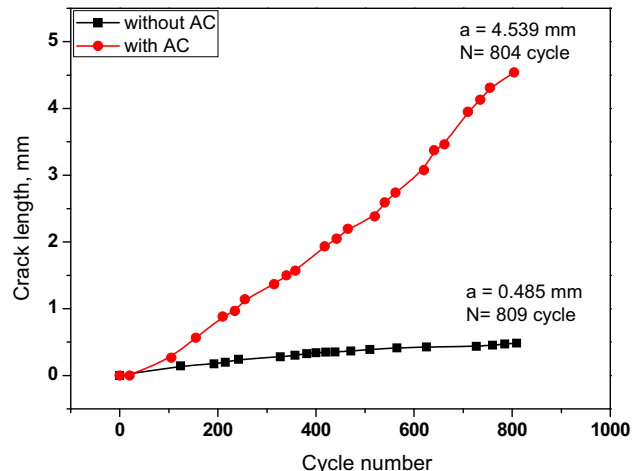


Fig. 3 Crack lengths of $\times 80$ steels with and without AC application vs. number of cycles

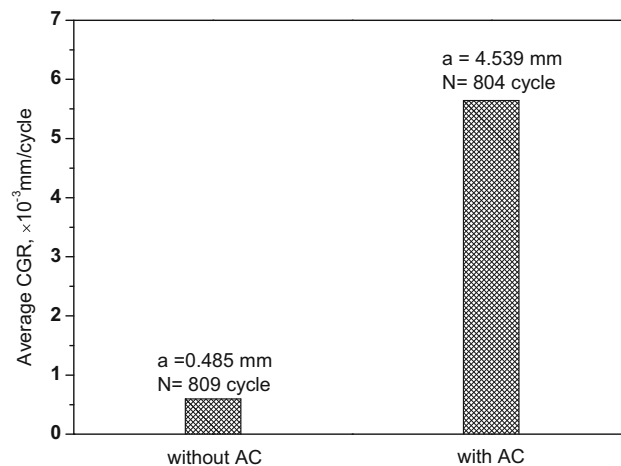


Fig. 4 The average crack propagation rates of $\times 80$ steels with and without AC application

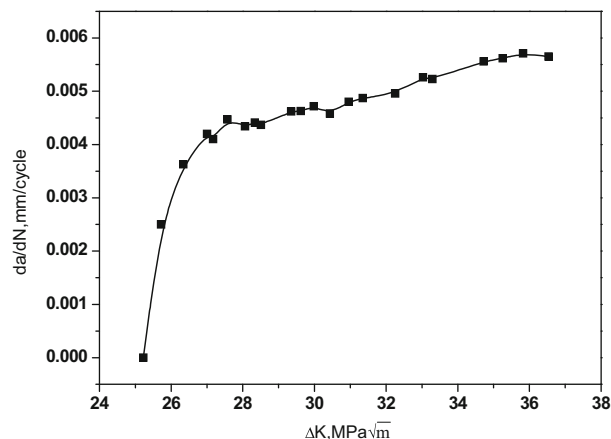


Fig. 5 CGR vs. ΔK in the presence of AC application

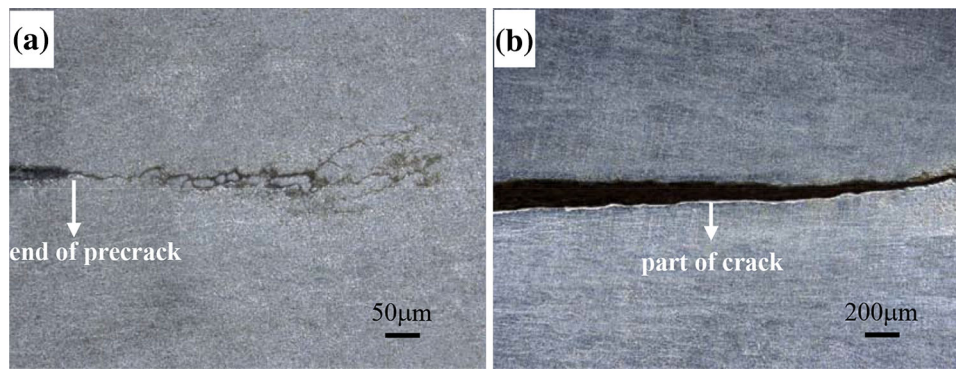


Fig. 6 Crack propagation morphologies of $\times 80$ steels with or without AC application: (a) without AC and (b) with AC

crack length of the steel tested in the presence of AC increases rapidly with the increase of cycle number, while the crack length increases slightly in the absence of AC current. At the same number of cycles, the crack length in the former case is significantly longer than the latter one. Therefore, for the conditions used the CGR of the steel with AC application is greater than that when no AC is applied. This demonstrates that the CGR of $\times 80$ steel in high pH solution is greatly enhanced by applying superimposed AC.

Figure 4 shows the average crack propagation rates of $\times 80$ steels under conditions with and without AC application. Under AC application, when the cycle number of the cyclic load test is 804, the crack length could reach up to 4.539 mm. In contrast, without the superimposed AC, the crack length is as short as about 0.485 mm at the cycle number of 809. By comparison, at the nearly same cycle number, the crack length of the steel tested in the absence of AC is much shorter than that with an AC application. As observed from the calculation, the average crack propagation rate (da/dt) of steel with the applied AC is 5.645×10^{-3} mm/cycle (7.056×10^{-6} mm/s), while that without AC application is 5.99×10^{-4} mm/cycle (7.48×10^{-7} mm/s). This indicates that there is a remarkable difference between the average crack propagation rates of $\times 80$ steels under conditions of with and without AC application. AC could accelerate the crack propagation rate of $\times 80$ pipeline steel in high pH solution.

It was reported that (Ref 9) the crack growth rates (CGR) of pipeline steel in near-neutral pH solution could reach up to 10^{-6} mm/s. In this paper, the CGR of steel under AC application is close to that of steel in a near-neutral pH-SCC. Therefore, these research results indicate that the crack propagation behavior is analogous to that of pipeline steel in near-neutral pH solution, which is shown in the previous literature (Ref 6).

Figure 5 shows the CGR versus ΔK in the presence of AC application. The crack propagation rate of $\times 80$ steel increases with the increasing ΔK . The range of da/dN is from 0 to 0.00565 mm/cycle. At the initial stage of crack propagation, the da/dN rapidly increases with the increasing ΔK , and then, the da/dN increases steadily. This indicates that the crack tip of the steel with AC application propagates more stably.

Figure 6 shows the crack propagation morphologies of $\times 80$ steels under conditions with and without AC application. Obvious differences in the crack propagation morphologies are observed between the specimens tested in the presence of AC and that without AC application. In the absence of AC, the crack is narrow, shallow and short. And the corrosion of the crack wall is slight. Moreover, a crack branching is observed,

and the crack propagation is flexural. All these characteristics are similar to that of classical intergranular fracture. In contrast, when AC is applied, the crack is very wide, deep and long. The crack propagation shows a straight line, and there is no crack branching phenomenon. In addition, the crack wall exhibits a severe corrosion phenomenon. Those features are analogous to the classical TGSCC (transgranular stress corrosion crack) fracture. The significant differences in these morphologies indicate that AC application could cause important effect on the crack propagation behavior of $\times 80$ steel and could enhance the crack propagation rate. It is also verified that the mechanism of high-pH SCC of pipeline could be changed due to the application of AC current (Ref 6). It may be noted that due to the very slow frequency of load cycling, a complex combination of SCC and corrosion fatigue is occurring.

4. Conclusions

The result of the crack propagation test shows that there is a significant difference between the crack propagation behaviors of $\times 80$ steels under conditions with and without the application of AC. The average crack propagation rates (da/dt) of the steels tested with and without AC application are 7.056×10^{-6} and 7.48×10^{-7} mm/s, respectively. The CGR of steel under superimposed AC condition is considerably greater than that without AC interference. AC accelerates the crack propagation rate of pipeline steel. The crack propagation behavior of steel under AC application in high pH solution is analogous to that in a near-neutral pH solution (TGSCC).

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