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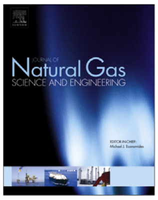

Experimental study on stray current corrosion of coated pipeline steel

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ABSTRACT

The experimental investigation on the coated pipeline steel was performed with respect to induced stray current including the alternating current (AC), direct current (DC), and the superimposed AC + DC sources in the soil-simulating conditions. The results showed that the corrosion potential and rate increased with the increases of stray current density. The extent of corrosion was found to be less in AC when compared to the DC sources. When an alternating current was superimposed on a direct current, the corrosion rate was larger than their respective corrosion. AC corrosion on the X70 pipeline steel represented three classic patterns, including the uniform corrosion, ring-like corrosion and pitting corrosion according to the geometrical shape of the corrosion images. The corrosion pattern would transfer to the local corrosion from the uniform corrosion, when the AC density increased. The quantity, area and depth of the corrosion pits arose with the increase of the AC current density. The relationship between the pit number or pit area and AC current density followed the power function, $y = ai^b$.

1. Introduction

The mild steel or carbon steel can usually suffer from the damage of the corrosion (Roy et al., 2014; Soltani et al., 2015; Hegazy et al., 2015; Shahabi et al., 2015). When a buried pipeline interacts with the surrounding environment, the pipeline has a strong corrosion if there is an electric current passes through. This process is called the stray current corrosion (Chen et al., 2013; Wang et al., 2014; Allahkaram et al., 2015). According to the different current through the pipeline, stray current is divided into two kinds, namely, alternating current (AC) and direct current (DC). In recent years, with the development of high voltage power lines and electrified railway, stray current corrosion problems become more prominent (Collet et al., 2001; Biase et al., 2010; Goidanich et al., 2010a; Goidanich et al., 2010b). The DC and AC corrosion behavior on the carbon steel had been introduced in the recent and extensive reviews (Revie and Uhlig, 2008; Nielsen, 2015; Castaneda and Rosas, 2015; Fitzgerald III, 2011). For a long time, people focus on DC corrosion and ignore the AC corrosion. The reason is that AC corrosion strength is much lighter compared to the equivalent DC corrosion (Chin and Sachdev, 1983; Wendt and Chin, 1985a, 1985b). But many reports indicate that AC corrosion damage could not be ignored (Linhardt and Ball, 2006; Panossian et al., 2010; Ormellese et al., 2011). Although Cathodic Protection (CP) system protects the pipeline, the system may be insufficient to prevent the AC corrosion. On the contrary, the system will happen sometimes polarity reversal under the AC interference. Worse still, the buried pipelines sometimes suffer the interference of AC & DC at the same time (Muralidharana et al., 2007). Therefore, the research on the corrosion behavior of metals under AC + DC interference has a high practical significance.

Corrosion of buried pipeline in the presence of stray current interference has been studied both experimentally and numerically in the past decades (Fu and Cheng, 2010; Yang et al., 2013; Kuang and Cheng, 2014). Up to now, the exact mechanism of AC corrosion is not fully understood and more research is required. The features extraction and analysis from metal corrosion image is a typical study of corrosion mechanism and corrosion diagnosis. The use of advanced materials characterization techniques in corrosion science is of great significance, for understanding of corrosion phenomena, especially the in-depth study of corrosion mechanism. It can not only provide evidence for some existing corrosion mechanism from the experimental data, but also can find some new phenomena to further improve and correct the existing mechanism of some assumptions from the microscopic mechanism of material damage (Codaro et al., 2002).

The corrosion behavior of X70 steel in the simulated soil conditions was investigated in this paper with emphasis on varying stray current densities. A series of experimental tests were conducted at varying AC densities with a fixed low DC density. Three

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different corrosion conditions were performed in our experiments, including an individual DC corrosion, an individual AC corrosion and mixed AC + DC corrosion.

2. Experimental work

2.1. Electrode and solution

The specimens used in this work were fabricated from a sheet of X70 pipeline steel, with a chemical composition (weight%): C (0.061), Si (0.24), Mn (1.53), P (0.011), S (0.0009) and Fe balance. The steel coupons were machined into 1 cm × 1 cm × 0.25 cm cubes, which were embedded in an epoxy resin, leaving a working area of 1 cm^2. The other areas were packaged with epoxy resins and curing agents. The wire was welded on the back area for the electrical connection, as shown in Fig. 1. All the specimens were firstly sanded step by step with waterproof abrasive papers of 800#, 1000#, 1200#. Then, they were polished by aluminium oxide of 0.5 μm. Thirdly, the acetone was used for the purpose of derosination. Next, we cleaned the specimens with the deionized water and the last we put them in a drying oven after dewatering with absolute ethyl alcohol.

The soil simulated solution in experiments were 0.05 M/L $NaHCO_3$, 0.1 M/L NaCl, and 0.1 M/L Na_2SO_4, respectively, which were prepared with chemically pure reagents. The experiments are simply a stagnant solution open to the air with no gas control. The experimental apparatus was put in a GDJS-408 constant temperature humidity chamber to decrease the effect of the environmental temperature on the corrosion process, and the temperature was set at 20 °C. A JJ98DD053A variable-frequency power source was employed to output the alternating current for the corrosion experiments, while the direct-current was generated by DH1718E DC power.

2.2. Stray current corrosion tests

The real-time potential of the steel electrode was measured and analyzed under various stray current densities. An indoor-accelerated corrosion test was designed to analyze the effects of alternating and direct currents on the buried pipelines and to understand the effects of the stray current densities on the corrosion rates. The switches, S1 and S2, were employed to switch the AC and DC circuits, as shown in Fig. 2.

In the DC corrosion experiments, the switch S2 was turned on, while the switch S1 was turned off. A DC milliammeter was employed to measure the current intensity. In this cycling circuit, the stray current flows out on Specimen 1, and it flows into on Specimen 2.

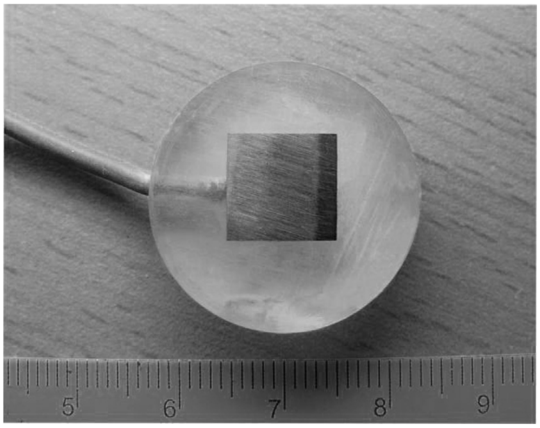

Fig. 1. Preparation of the specimens for AC corrosion after epoxy-based resin application.

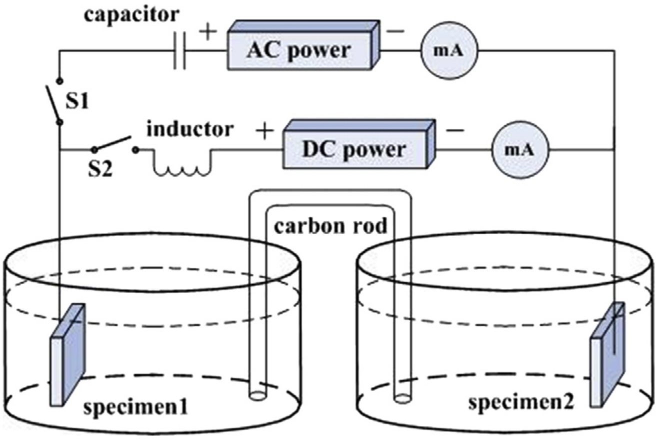

Fig. 2. Schematic diagram of the experimental setup for stray current corrosion.

In the AC corrosion tests, on the contrary, we turned on the switch S1 and turned off the switch S2. In the AC circuit, the current intensity was measured by using an AC milliammeter. The AC signal with a frequency of 50 Hz sinusoidal wave was applied between the Specimen 1 and the Specimen 2.

In the AC + DC corrosion experiments, both the switches S1 and S2 were turned on. The capacitor and inductor were used to segregate the AC and DC circuits so that the current can flow in their respective circuits. A platinum electrode of 4 cm^2 was employed to be an auxiliary electrode instead the Specimen 2.

All the immersion tests were conducted under AC, DC or AC + DC densities of 0–500 A/m^2 for 7 days. The weightlessness measurement was performed together with the packaging. As we knew, the encapsulation of sample was a key point in the corrosion test. For avoiding its influence, we adopted the parallel experiments with three packaged sample. And every experiment was also repeated three times to obtain an averaged weight loss.

After the test, the specimen was put directly in a drying oven for dewatering after the immersion tests. Then the surface corrosion products were wiped with fresh water and a soft brush. Next, the corrosion test specimens were put in the rust cleaning solution for 10 min to clear the compact corrosion scales adhered to the surface. Lastly, the specimens were washed with distilled water and dried by warm flowing air. The corrosion rate was calculated as follows:

$$V_{\mathrm{corr}} = \frac{K \cdot \Delta W}{S \cdot T \cdot D} \tag{1}$$

where V_{corr} is the corrosion rate, mm/y; K is a constant, $8.76^{*}10^4$; S is the specimen area, cm^2; T is the corrosion time, h; D is the specimen density, g/cm^3; ΔW is the real weight loss, g.

2.3. Surface characterization

The micro structural examination of the corroded specimens was carried out using a Stereo Microscope incorporated with image analyzing software. The surface topography of corroded X70 steel was evaluated by scanning electron microscopy (SEM) in order to study the morphology and evolution of corrosion products formed on the surface of the X70 steel.

The MATLAB software was used to carry on binarization processing for pre-processed grayscale images. The MIAPS multifunctional image processing software was employed to extract the

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