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Effect of alternating voltage on corrosion of X80 and X100 steels in a chloride containing solution – Investigated by AC voltammetry technique

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ABSTRACT

AC corrosion of the X80 and X100 steels in 0.1 M NaCl solution were studied by the AC voltammetry technique. Corrosion electrochemical kinetics and solid/solution interface structure changes under the influence of AC voltage were characterized. Results illustrate that corrosion potential of the two steels shift negatively with the increase of AC amplitude and decrease of AC frequency. The anodic processes are under charge-transfer control and the anodic Tafel slopes increase with the increase of AC magnitude. The cathodic processes are under diffusion control at low AC amplitudes, while they become increasingly under charge-transfer control with higher AC amplitudes.

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1. Introduction

AC corrosion is becoming the new threat to pipeline integrity due to the increasing development of high-voltage power transmission, rail transit systems and their sharing common right-of-way with the pipes [1]. Although there have been increasing reports of AC-induced corrosion in the past two decades, the subject remains controversial.

Different theories have been proposed about the mechanism of AC corrosion. Yunovich and Thompson [2] presented that the oxidation current produced by the anodic half wave of AC was greater than that decreased during the cathodic half wave due to the non-linear relationship between potential and current, which resulted in a net oxidation current greater than the free-corrosion current. Nielsen et al. [3] developed an electrical equivalent diagram to model the AC-corrosion process, assuming that the exchange current densities and the Tafel slopes did not change with time. They indicated that the AC-corrosion rate was controlled by kinetic parameters and amplitude of the AC-voltage subtracted by the IR-drop existing across soil resistance. Chin and Venkatesh [4] and Lalvani and Lin [5] pointed out that the ratio of the anodic and cathodic Tafel slope determined the sensitivity of AC corrosion. Goidanich et al. [6,7] investigated the effect of AC on various corrosion kinetic parameters such as Tafel slopes and exchange current densities of carbon steel, galvanized steel, zinc and copper. They found that the effect of AC on kinetic characteristics depended on the system studied and on the AC current density applied. Bosch and Bogaerts [8] attempted to model the effects of AC on polarization curves mathematically. A relation that relates the AC-induced voltage with the corrosion potential and corrosion rate was derived. It was reported that the AC corrosion depended strongly on the Tafel parameters. But the model which predicted that corrosion current and corrosion potential were independent on the frequency of the applied signal was in contradict with the experimental results displayed previously. Recently, a more accuracy model in consideration of the double-layer capacitance and the solution resistance was proposed by Lalvani et al. [9,10] and derived that an increase in the frequency lowered the corrosion current.

To investigate the AC influence on electrochemical kinetics of the anodic and cathodic reactions, electrochemical tests have been carried out. The commonly used method is by means of an electrical circuit specially designed for polarization measurements under the influence of AC [6,11]. The electrical circuit has two different meshes: the AC mesh is used to supply AC signals by an AC feeder and a capacitor is connected in series to block DC signals; the DC mesh contains a potentiostat which is used to measure polarization curves and an inductor used for preventing AC current from flowing into the potentiostat. Although the current signals between the DC mesh and the AC mesh is blocked by the capacitor and the inductor, magnetic interference still exist between the AC

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generator and the potentiostat. Even if the two instruments are both grounded, a ground loop error can still occur because of the impedance between the two connections and the noise current flowing through the impedance [12], which influences the accuracy and stability of the measured polarization curves.

The purpose of the above electrical circuit design is to allow separating, controlling and measuring DC and AC, which can be achieved by an electrochemical workstation alone. An electrochemical workstation is a combination of potentiostat, galvanostat and frequency response analyzer specially designed for DC/AC potential (or current) application and DC/AC current (or potential) acquisition [13]. The control module of the workstation allows the application of the AC and the DC signals separately, while the measuring module enables the separate measurement of the AC and the DC signals [14]. Intra-system interferences are eliminated by electric wave filters or filter circuits [15]. In this work, we used the AC voltammetry technique in an electrochemical workstation to characterize the corrosion polarization properties and the solid/solution interface structure changes of the X80 and X100 high strength low alloy pipeline steels in a chloride containing electrolyte under the influence of AC voltage.

2. Experimental

2.1. Materials and solution

The materials studied are the API X80 and X100 high strength low alloy pipeline steels. The chemical compositions of the two steels are shown in Table 1. The microstructures of the steels were observed by Quanta 250 Scanning Electron Microscopy after polishing and etching with 4% nitric acid-alcohol solution.

The electrochemical experiments were performed in 0.1 M NaCl solution, which was made from analytic grade reagents (Fisher Scientific) and ultra-pure water (18 MΩ cm in resistivity). The pH of the solution was close to 7.

2.2. Electrochemical tests

The X80 and X100 steels with the dimension of 10 mm × 10 mm × 3 mm, as working electrodes, were coated with epoxy resin and leaving an exposure surface area of 1 cm^2. The working surface of the electrodes were ground sequentially up to 2000 grit emery paper, followed by rinsing with double-distilled water and finally dried with ethanol. The electrochemical tests were performed at a Princeton 2273 PARSTAT for which a conventional three-electrode electrochemical cell was used as shown in Fig. 1, where the counter electrode was a sheet of Pt and a saturated calomel electrode (SCE) served as the reference electrode.

Potentiodynamic polarization curves of the two steels without superimposed AC voltage were measured from -1.2 to $0\ V_{SCE}$ with the scanning rate of 1 mV/s. AC voltammetry measurements (Mott–Schottky tests in Princeton 2273 PSTAT) were performed to the working electrodes with a DC potential ranging from -1.2 to $0\ V_{SCE}$. The 50 Hz AC voltage signals at fixed amplitude (100 mV, 200 mV, 300 mV, 400 mV, 500 mV, 600 mV, 800 mV and 1000 mV in rms) were superimposed to the X80 and X100 steels to characterize the influence of AC magnitude. The influence of AC frequency on the X80 steel was investigated by the application of $300\ mV_{rms}$ and $400\ mV_{rms}$ AC at 5 Hz, 50 Hz, 500 Hz, 5000 Hz, respectively. While the influence of AC frequency on the X100 steel was studied by the AC voltages of $200\ mV_{rms}$ and $300\ mV_{rms}$ at 5 Hz, 50 Hz, 500 Hz, 5000 Hz, respectively. All tests were performed at ambient temperature (about 22 °C) and repeated at least three times to insure the reproducibility of the tests.

2.3. Data presentation

The AC voltammetry technique is a computer program that applied single-frequency and constant amplitude of AC voltages on a DC voltage scan with virtual instrument [16]. The signals imposed on the working electrodes are shown in Fig. 1. By using AC voltammetry technique, a potential signal of $E = E_{DC} + E_{AC}$ is applied to the working electrodes, where E_{DC} is a staircase shape DC potential scanning from -1.2 to $0\ V_{SCE}$ with the step size of 1 mV, and E_{AC} is a single sinusoidal voltage with the frequency of f and the amplitude of E_p. The DC voltage elicits a time-varying DC current I_{DC}, while the AC current produced by the AC voltage consists of a faradaic origin and a non-faradaic element arising from the double-layer capacitance. The plot of E_{DC} vs. $\log I_{DC}$ is cor-

Table 1
Chemical compositions of the X80 and X100 steels (wt.%).

Material	C	Mn	Si	S	Cr	Ni	Cu	Al	Ti	Mo	V	Nb	N
X80	0.036	1.771	0.197	0.002	0.223	0.278	0.22	0.021	0.019	0.184	0.001	0.11	0.005
X100	0.06	2.095	0.243	0.001	0.346	0.41	0.301	0.054	0.014	0.381	0.007	0.127	0.003

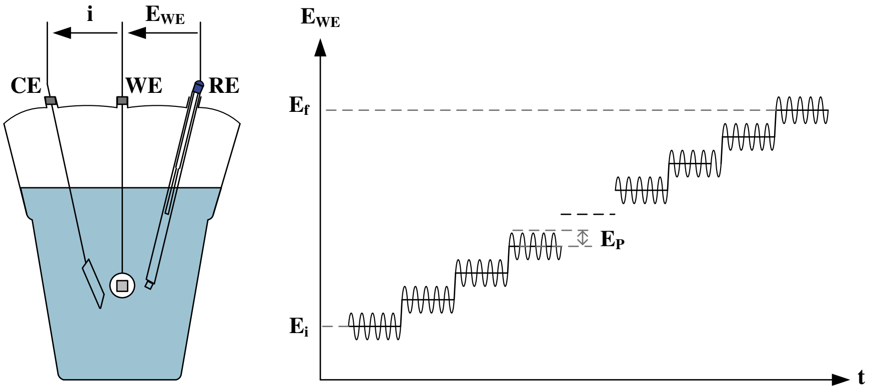

Fig. 1. Potential signals applied to the working electrode by AC voltammetry technique. It consists of a staircase shape DC potential scanning from E_i to E_f and a sinusoidal AC voltage.

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