Available online at www.sciencedirect.com
ScienceDirect
Electrochimica Acta 52 (2007) 6811–6820
ELECTROCHIMICA Acta
www.elsevier.com/locate/electacta

Effect of ethylenediamine tetraacetic acid disodium on the corrosion of cold rolled steel in the presence of benzotriazole in hydrochloric acid

Qing Qu [a,*], Shuan Jiang [a], Wei Bai [b], Lei Li [c]

[a] *Department of Chemistry, Yunnan University, Kunming 650091, China*
[b] *Department of Chemistry, Yunnan Nationalities University, Kunming 650092, China*
[c] *Laboratory for Conservation and Utilization of Bio-Resources, Yunnan University, Kunming 650091, China*

Received 5 February 2007; received in revised form 26 April 2007; accepted 26 April 2007
Available online 10 May 2007

Abstract

The inhibition behavior of cold rolled steel in 0.1 M hydrochloric acid (HCl) by ethylenediamine tetraacetic acid disodium (EDTA) in the absence and presence of benzotriazole (BTA) was investigated with Tafel polarization curve and electrochemical impedance spectroscopy (EIS). The polarization curve results show that the single EDTA acts as an anodic type inhibitor while the combination of EDTA and BTA acts as mixed type inhibitor and mainly inhibits anodic reaction. All impedance spectra in EIS tests exhibit one capacitive loop which indicates that the corrosion reaction is controlled by charge transfer process. Inhibition efficiencies obtained from Tafel polarization, charge transfer resistance (R_t) are consistent. The corrosion of cold rolled steel in 0.1 M HCl is obviously reduced by EDTA in combination with lower concentrations of BTA. Fourier transform infrared spectroscopy (FTIR) and atomic force microscopy (AFM) were used to characterize the corrosion surface of cold rolled steel. Probable mechanisms are present to explain the experimental results.

Keywords: EIS; Tafel polarization curve; Cold rolled steel; EDTA; BTA

1. Introduction

Hydrochloric acid solutions are widely used for acid clearing, industry cleaning, acid descaling and oil-well acidizing, etc. Therefore, corrosion inhibitors for hydrochloric acid have attracted more attention because of wide application [1–6].

In most inhibitor studies, the formation of donor–acceptor surface complexes between free or pi-electrons of an inhibitor and vacant d-orbital of metal was proposed [1,7–9]. Thus, compounds with nitrogen and oxygen function group are considered to be one of the effective chemicals for inhibiting the corrosion of metals [1,8–11].

EDTA is the most commonly used as chelating agent containing nitrogen and oxygen function group, which has been found widespread industrial use in electrodeposition [12], metal recovery [13], separation of V^{4+} and V^{5+} [14] and chemical decontamination for metal deposits [15,16] because of its strong metal complexing properties. Due to the widespread application of EDTA, some researchers studied the corrosion of metals in EDTA solutions [17,18]. Yao et al. [17] studied the corrosion behavior of 20A carbon steel in 4% EDTA solution using steady-state polarization curve method at 30 °C and corrosion rates at various temperatures, their results showed that the corrosion progress was controlled by both hydrogen evolution and oxygen reduction reactions in the temperature range of 30–150 °C. Padma et al. [18] investigated the effects of various additives such as PH additive, reducing agent, oxidizing agent and corrosion inhibitor on the corrosion of carbon steel and Monel-400 alloy in EDTA based steam generator cleaning formulations. Furthermore, Studies on the effect of EDTA on the corrosion and film formation of metals in various media have also been reported [19–22]. For example, Milošev et al. [19,20] studied the corrosion of the stainless steel in the physiological solutions, their results indicated that the addition of EDTA induced increase in metal dissolution and disturbed the formation of the passive layer. However, researches by Gadiyar et al. [21] showed that EDTA could inhibit the corrosion of carbon steel, but the inhibitive effect was not very excellent. Capobianco et al. [22]

* Corresponding author. Tel.: +86 871 5035798; fax: +86 871 5036538.
E-mail addresses: quqing58@yahoo.com.cn, quqing@ynu.edu.cn (Q. Qu).

0013-4686/$ – see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.electacta.2007.04.114

investigated the effect of EDTA-hydroxylamine sulfate-Fe^{2+} on the corrosion of type 316L stainless steel in the industrial crystallization plant, their results showed that the system was an effective inhibitor of the corrosion of the steel.

Additionally, Bennett et al. [23] investigated the antimicrobial properties of triazole compounds (containing BTA); they found that the inhibitory actives of triazole compounds were markedly potentiated when employed in conjunction with EDTA in metalworking fluids. So it is interesting in studying the corrosion of steel in the presence of triazole compounds and EDTA because of their potential use in metalworking fluids.

BTA is a heterocyclic compound which can effectively inhibit the corrosion of copper [24–26]. Furthermore, BTA used as an inhibitor for steel in acid solutions has been reported [27,28]. For example, Gomma [27] investigated the corrosion inhibition of steel by BTA in sulphuric acid, their results revealed that the corrosion rate depended on the concentration of BTA and chloride ions along with the sweep rate of polarization, and the maximum inhibition efficiency was obtained at 9×10^{-3} M BTA. A study by Bellaouchou et al. [28] indicated that BTA affected both anodic and cathodic process of corrosion inhibition under heat transfer of 904L stainless steel in phosphoric acid, and the highest inhibition efficiency was obtained at 0.1 M BTA. Generally speaking, higher inhibition efficiency of BTA is only obtained at higher concentration. In order to increase the inhibition efficiency in lower concentration of BTA, some researchers studied the synergistic effects of BTA and other compounds [29,30]. However the combined effect of EDTA and BTA on the corrosion of carbon steel has not yet been reported.

The objective of this investigation is to determine the combined effect of EDTA and BTA on the corrosion of cold rolled steel. Meanwhile, probable inhibitive mechanisms are presented to explain the experimental observations.

2. Experimental method

2.1. Materials

The experiments were performed with cold rolled steel specimens with the following chemical composition (wt.%): $C \leq 0.05$, $Si \leq 0.02$, $Mn \leq 0.28$, $S \leq 0.023$, $P \leq 0.019$, Fe remainder.

Ethylenediamine tetraacetic acid disodium (EDTA), benzotriazole (BTA) and hydrochloric acid (HCl) used were of analytical grade. All solutions were prepared from distilled water.

2.2. Electrochemical measurements

A three-electrode system including a working electrode, an auxiliary electrode and a reference electrode was used for electrochemical measurements in 250 mL solution. The working electrodes were made of the steel specimen in PVC holder using epoxy resin with an exposed area of $1.0\,cm^2$, polished with emery paper from 100 to 800 grades on the test face, rinsed with distilled water, degreased with acetone (CH_3COCH_3), and dried with a warm air stream. The auxiliary electrode is a platinum foil and the reference electrode is a saturated calomel electrode (SCE) with a Luggin capillary positioned close to the working electrode surface in order to minimize ohmic potential drop. The working electrodes were immersed in the test solution at open circuit potential for 2 h before measurement until a steady state appeared. All electrochemical measurements were carried out PAR 2263 Potentiostat/Galvanostat (Princeton Applied Research). EIS was carried out in a frequency range of 0.1 Hz to 10^5 Hz using a 10 mV peak-to-peak voltage excitation. The Tafel polarization scan was carried out by polarizing to ±250 mV with respect to the free corrosion potential (E_c) at a scan rate of $0.5\,mV\,s^{-1}$. Each experiment was repeated at least three times to check the reproducibility.

2.3. AFM studies

Prior to monitor the topographic changes of the electrode surface, the cold rolled steel specimens were abraded with emery paper from 100 to 800 grades, and then washed with distilled water and acetone. After immersion in 0.1 M HCl without and with addition of inhibitors at 20 °C for 6 h, the specimens were cleaned with distilled water and acetone, then dried with a cold air blaster, and then used for a Japan instrument model SPA-400 SPM Unit atomic force microscope examinations.

2.4. FTIR studies

In order to investigate the adsorption behavior of inhibitors on the surface of cold rolled steel, Model Magna-IR 560 FTIR combined with InspectIRTM FTIR microanalysis and video imaging accessory was used to measure the spectra of the corroded surface of cold rolled steel in HCl with BTA and EDTA, all the spectra in these experiments were obtained by adding 64 interferograms at a resolution of $8\,cm^{-1}$ in the region from 650 to $4000\,cm^{-1}$.

3. Experimental results and discussion

3.1. Electrochemical studies

3.1.1. Tafel polarization

The corrosion rates (CR) of cold rolled steel in 0.1 M HCl in the absence and presence of inhibitors were calculated from corrosion current density (I_{corr}) values using the following equations (1) and (2):

$$\mathrm{CR\,(mpy)} = C \times \frac{\mathrm{EW} \times I_{corr}}{d} \quad (1)$$

where EW is the equivalent weight of the sample in g, I_{corr} is the corrosion current density in $A\,cm^{-2}$, d is the density of sample in $g\,cm^{-3}$ and C is a conversion constant equal to 1.287×10^5, respectively.

The inhibition efficiencies (IE_p) from Tafel polarization were obtained by the following relationship [1]:

$$\mathrm{IE_p} = \frac{I_{corr(0)} - I_{corr(inh)}}{I_{corr(0)}} \times 100 \quad (2)$$