J MATER RES TECHNOL. 2015;4(4):423–428

Available online at www.sciencedirect.com

jmr&t
Journal of Materials Research and Technology
www.jmrt.com.br

Original Article

Passivation behavior of a ferritic stainless steel in concentrated alkaline solutions

*Arash Fattah-alhosseini**, *Saeed Vafaeian*

Department of Materials Engineering, Bu-Ali Sina University, Hamedan, Iran

ARTICLE INFO

Article history:
Received 18 June 2014
Accepted 4 February 2015
Available online 12 March 2015

Keywords:
Alkaline solution
Ferritic stainless steel
Mott–Schottky
Donor density

ABSTRACT

The passivation behavior of AISI 430 ferritic stainless steel was investigated in concentrated alkaline solutions in relation to several test parameters, using electrochemical techniques. Increasing solution pH (varying from 11.5 to 14.0) leads to an increase in the corrosion rate of the alloy. Mott–Schottky analysis revealed that passive films formed on AISI 430 ferritic stainless steel behave as n-type semiconductor and the donor densities increased with pH. Electrochemical impedance spectroscopy (EIS) results showed that the reciprocal capacitance of the passive film is directly proportional to its thickness, which decreases with pH increase. The results revealed that for this ferritic stainless steel in concentrated alkaline solutions, decreasing the solution pH offers better conditions for forming passive films with higher protection behavior, due to the growth of a much thicker and less defective film.

1. Introduction

Proton exchange membrane fuel cell (PEMFC) has widely attracted an attention. Bipolar plates are important components in PEMFC and stainless steel is popularly used as bipolar plate material. In the recent years, many studies on stainless steel bipolar plate material have been on austenitic steels [1–5]. Also, there were some works on the effects of various factors such as acidity, fluoride ions, temperature and polarization potential on the corrosion behavior of the austenitic stainless steel bipolar plates [6–10].

Former investigations showed that the effectiveness of the austenitic stainless steels determined by the quantity of Cr, with higher Cr leading to better behavior [6–9]. However, austenitic stainless steels have a high Ni content, which increases their cost. Generally, former works on the nature of the passive film formed on austenitic stainless steels revealed that Ni is not a major component of it. This indicates that Ni could be eliminated without changing the passivation effectiveness [5]. Also, Wind et al. [11] reported that Ni from AISI 316L austenitic stainless steel can be a major contaminant in the membrane, reducing the total conductivity. Thus far, there has been very little research on ferritic stainless steels,

---

* *Corresponding author.*
E-mail: a.fattah@basu.ac.ir (A. Fattah-alhosseini).

http://dx.doi.org/10.1016/j.jmrt.2015.02.003

which have low or no Ni but similar Cr contents. Therefore, the selection of a ferritic stainless steel was chosen for this work.

In the polymer electrolyte membrane fuel cell, the interfacial contact resistance is influenced by the material property, surface topology, operation condition and the property of the passive film such as the composition and thickness [12]. Of late, there have been several methods to modify the property of the passive film (such as the electrochemical surface treatment [13] and the addition of the alloying element [14]). Moreover, the immersion in the alkaline solution is one of the useful methods to improve the properties of the passive film. In NaOH solutions, the passive film transforms from iron oxide-rich film to passive film enriched with chromium oxide and depleted in iron oxide [12,15].

Generally, increasing research on the electronic properties of passive films formed on stainless steels has given an important contribution to the understanding of the corrosion behavior of these alloys. In practice, the passive film composition varies with the solution pH used for film formation and this is expected to affect the semiconducting properties of the passive film [16,17]. According to the point defect model (PDM) [18–20], the growth of the passive film involves the migration of these point defects under the influence of the electrostatic field in the film. Thus, the key parameters in determining the transport of point defects and hence the kinetics of film growth is the density and the diffusivity of the defects in film. In the last decade, by employing the Mott–Schottky analysis in conjunction with the PDM, the point defects density and diffusivity for some metals and alloys have been determined [18–20].

In this work, the EIS and Mott–Schottky analysis of AISI 430 ferritic stainless steel in NaOH solutions at open circuit potential (OCP) was performed and the passivation parameters and defects concentrations were calculated as a function of pH solution. Also, the relationship between the donor density and pH solution are discussed in order to understand the passivation characteristics of AISI 430 ferritic stainless steel.

2. Experimental procedures

The chemical composition of AISI 430 ferritic stainless steel is shown in Table 1. All samples were ground to 2000 grit and cleaned with distilled water prior to tests. Aerated alkaline solutions (without purging oxygen or any gas) with NaOH and distilled water were prepared at different pH (11.5, 12.0, 12.5, 13.0, 13.5, and 14.0).

The electrochemical measurements were performed in the following sequence:

(a) Potentiodynamic polarization curves were measured potentiodynamically at a scan rate of 1 mV s^{-1} starting from −0.25 V (vs. OCP).
(b) EIS test at OCP DC potential with AC potential perturbation amplitude of 10 mV and frequency range of 100 kHz to 10 mHz.
(c) Mott–Schottky analysis was carried out on the passive films at a frequency of 1 kHz using a 10 mV ac signal and a step potential of 25 mV, in the cathodic direction.

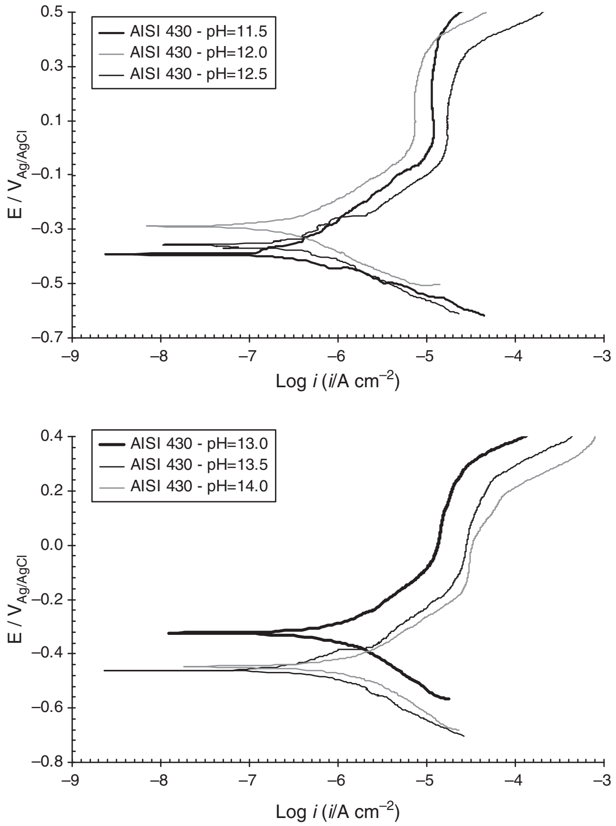

Fig. 1 – Potentiodynamic polarization curves of AISI 430 stainless steel in NaOH solutions with pH varying from 11.5 to 14.0.

Before all electrochemical tests, the working electrodes were immersed in the investigated solutions at OCP to form a steady-state passive film. All electrochemical measurements were performed in a conventional three-electrode flat cell. The counter electrode was a Pt plate, and all potentials were measured against Ag/AgCl in saturated KCl. All electrochemical measurements were obtained using Autolab potentiostat/galvanostat controlled by a personal computer. For the EIS data modeling and curve-fitting method, the NOVA impedance software was used.

3. Results and discussion

3.1. *Potentiodynamic polarization measurements*

Fig. 1 shows the potentiodynamic polarization curves of AISI 430 ferritic stainless steel in NaOH solutions with pH varying from 11.5 to 14.0. By comparing the polarization curves for this stainless steel in different pH solutions, the current density was found to increase with potential during the low polarization range and no obvious current peak was observed. Also, all curves exhibit similar features, with a broad passive range up to the onset of transpassivity.

Tafel extrapolation method is widely used for the measurement of the corrosion rate. By this method, the corrosion current density (i_{corr}) was calculated of the linear part for the