STAINLESS STEEL AS A MATERIAL FOR FUEL-CELL BIPOLAR PLATES

Tomáš LOVAŠI, Milan KOUŘIL, Tereza JAMBOROVÁ, Vojtěch PEČINKA

University of Chemistry and Technology Prague, Department of Metals and Corrosion Engineering, Prague, Czech Republic, EU, lovasit@vscht.cz

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Abstract

Stainless steels are considered to be a perspective candidate as a bipolar plate material for the polymer electrolyte membrane fuel cells. The main reasons for using this material are properties such as low cost, high strength, electrical and heat conductivity and reasonable corrosion resistance. The aim of this study was to test several stainless steels in simulated environment (acidic and humid environment at 80 °C) for application as bipolar plates. The experiments were carried out in an electrolyte of pH 3 with addition of 0.1 ppm HF. Potentiodynamic and potentiostatic polarization according to United States Deparments of Energy was used for electrochemical testing. Open circuit potential, polarization resistance, corrosion current density and corrosion rate from the Tafel extrapolation were determined on the basis of measured data. The suitability of using different types of stainless steels as a bipolar plate material for fuel cell has been evaluated.

Keywords: Stainless steels, corrosion, bipolar plates

1. INTRODUCTION

As a replacement for a combustion engine, the use of polymer electrolyte membrane fuel cells (PEMFC) is being considered in the near future to convert chemical energy into electrical energy. [1,2]. The fuel cell itself should have a number of positives over a conventional combustion engine. The main advantages are for example eco-friendliness (noise and emissions), low-temperature work, allowing faster start-up and immediate response to changing performance and greater energy efficiency. [3,4]. At present, there are several shortcomings that defend greater use of fuel cells in normal practice. An example is the price which is associated with their production and the need to reduce weight and volume when considering use in automobile transport [5]. Due to the large number of requirements that are put on fuel cells, DOE limits (US Department of Energy) have been developed to provide sufficient durability and performance. [6]. DOE requirements are summarized in **Table 1**. The price of the fuel cell is reflected in the price of the material used for the individual components, while the cost of the bipolar plates is significant part of the price. PEMFC consist of two essential parts, a gas diffusion layer and a catalyst layer (MEA - membrane electrode assembly), which are placed between the bipolar plates. The solid electrolyte in the PEMFC is a membrane. The most commonly used membrane - perfluorosulfonic acid-base polymer (PFSA) - has a main chain formed by Teflon and side chains terminated by sulfonic acid groups (HSO_3) [5]. As for the bipolar plates themselves (sometimes also called end plates, depending on the design), they are made of graphite or carbon composite because of its electrical properties and chemical stability. However, the disadvantages of this material are its fragility and porosity. Material to bipolar plates is required to meet the current DOE limits. Therefore, it is necessary to find a suitable substitute for graphite. Therefore, current research has been focused on the use of metallic materials using conductive coatings with corrosion-resistant properties [7]. Major non-ferrous metal candidates include titanium, copper, nickel, magnesium or aluminum and their alloys (and alloys of these metals). The disadvantage of these materials is that they must be coated, or their purchase price is high. Another possible substitute being tested is stainless steel [8-11]. This material is very perspective due to the combination of good mechanical properties, electrical and thermal conductivity. It is also affordable and relatively easy to machine. Stainless steels are prone to corrosion in an environment where the fuel cell should be operated. However, corrosion resistance can be increased by coating as in non-ferrous metals. Most attention is focused on austenitic stainless steels, especially steels AISI 316L. Austenitic stainless steels 304, 310 and 316 are less tested. Superaustenitic stainless steels such as 254SMO and 904L or duplex stainless steels such as 2205 are also considered [12,13].

Table 1 DOE limits

Characteristic	**2020 Target**	**Notes**
Cost	<3 \$ kW^{-1}	2002 dollars, 500,000 stacks per year
Corrosion resistance (anode)	<1 μA cm^{-2}	pH 3, 0.1 ppm HF, 80 °C, Ar purge Potentiodynamic test -0.4 V-0.6 V (Ag/AgCl), 0.1 mV/s
Corrosion resistance (cathode)	<1 μA cm^{-2}	pH 3, 0.1 ppm HF, 80 °C, aerated Potentiostatic test (>24 h) 0.6 V (Ag/AgCl), $i_{passive}$ <50 nA cm^{-2}
Electrical conductivity	>100 S cm^{-1}	-
Areal specific resistance	<0.01 Ω cm^{2}	including contact resistance at 138 N cm^{-2}
Hydrogen premeability	<1.3.10^{-14} cm^{3}	ASTM D1434, 80 °C, 3 atm, 100 % RH
Flexural strength	>25 MPa	ASTM D790-10
Forming elongation	40 %	ASTM E8M-01

2. EXPERIMENT

2.1. Specimens and simulated solutions

For this study was chosen two type of stainless steel, AISI 316L and super-austenitic AISI 904L. Chemical composition of the steel specimens used in this study is shown in **Table 2**.

Table 2 Main chemical composition of study steels

Element (wt. %)	C	Cr	Ni	Mo	Mn
316L	< 0.03	16 - 18	10 - 12	2 - 2.5	2
904L	< 0.02	19 - 21	24 - 26	4 - 5	2

The specimens were machined into cylinders with diameter 16 mm. Before exposure, the working surface of specimen was polished with 1200 grit silicon carbide abrasive paper, rinsed with distillated water and ethanol and dried. The microstructure of stainless steel 361L is shown in **Figure 1.**

Figure 1 The microstructure of AISI 316L

Before every measurement was prepared fresh simulated solutions. The model solution was prepared a mixture with 1 ml of 0.01 % hydrofluoric acid and demineralized water. Sulfuric acid was used to adjust the pH to value 3. Concentration on this acid was 1M and was added into solution dropwise.

2.2. Electrochemical measurements

The electrochemical experiments were carried out in a corrosion cell consisting of a three-electrode arrangement. Model solution in corrosion cell was heated with using thermostat on temperature 80 °C and was mixed for homogeneous temperature in full volume of the corrosion cell during the electrochemical

measurements. The specimen served as the working electrode and platinum wire was used as a counter electrode. A platinum sheet with area 0.5 mm^2 was used as a reference electrode. A saturated calomel electrode was connected with salt bridge (filled whit simulated solution). This electrode was used to measure the open circuit potential of platinum sheet in a corrosion cell. A Zahner Zennium electrochemical workstation was used to perform the electrochemical measurements and the Thales XT Analysis software was used for electrochemical data processing. Each experiment was repeated two times to ensure reproducibility of the results. The electrochemical measurement consisted of measuring the open circuit potential for 1800 seconds. This was followed by a measurement of polarization resistance (± 20 mV/OCP, scan rate 0.1 mV/s). Measurement of potentiodynamic curves was the last measurement. Setup for cathodic part of polarization curve was +100mV OCP -1.2V with scan rate 5 mV/s. For the anodic part, the scan rate was the same, while the sample was polarized in the range -100 mV OCP 1.5V.

3. RESULTS AND DISCUSSION

After the specimen was immersed in corrosion simulated solution, the corrosion potential E_{corr} and the current density i_{corr} can be measured by an electrochemical method. Corrosion potential and current density are widely used as indicators of the material corrosion resistance. A high corrosion potential and low current density indicate that corrosion of material is retarded. **Figure 2** shows potentiodynamic polarization curves for stainless steel 316L and 904L in model solution at 80 °C.

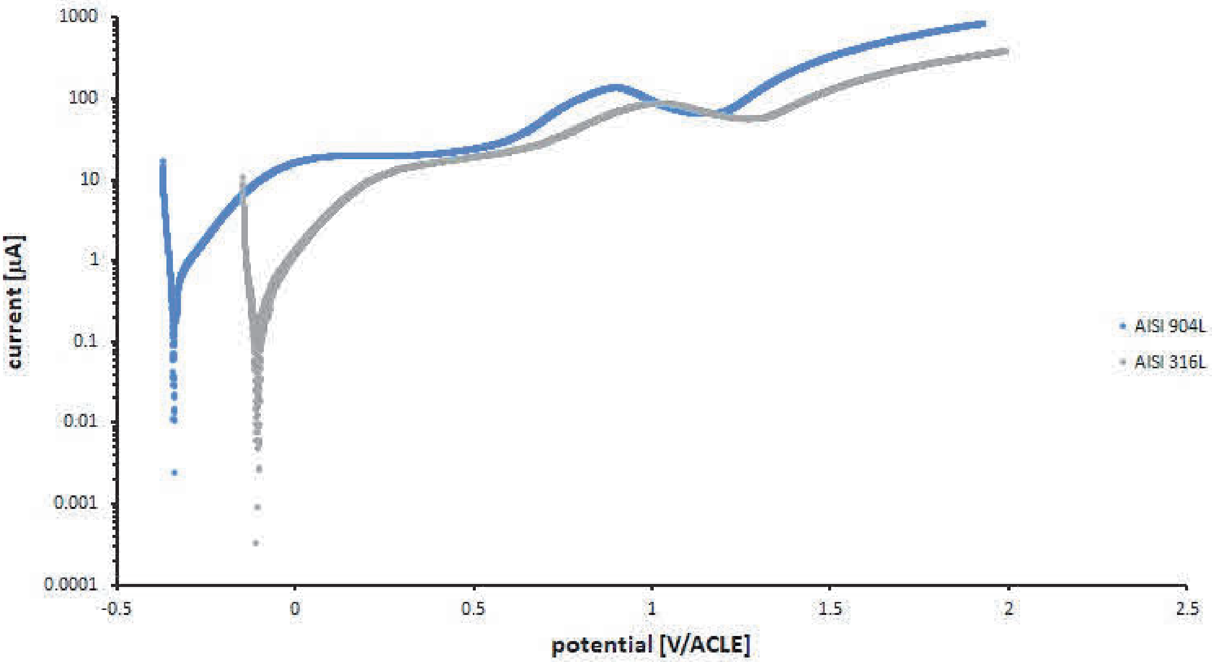

Figure 2 Anodic part of polarization curves of stainless steel AISI 316L and 904L in model solution at 80 °C

The values of the relevant electrochemical parameters, i.e., corrosion potential (E_{corr}), corrosion current density (i_{corr}), anodic (β_a) and cathodic (β_c) Tafel slopes, are extracted from the potentiodynamic polarization curves and are summarized in **Table 3**. These data were obtained by fitting the polarization curves shown in **Figure 2** and **Figure 3**. The polarization resistance values were obtained from the measured data, which were evaluated in the range of ± 10 mV/OCP. It can be seen in **Figure 3** that the cathodic Tafel slope (β_c) is very similar. While in the anodic Tafel slope (β_a), a passive region appears of steel 904L.

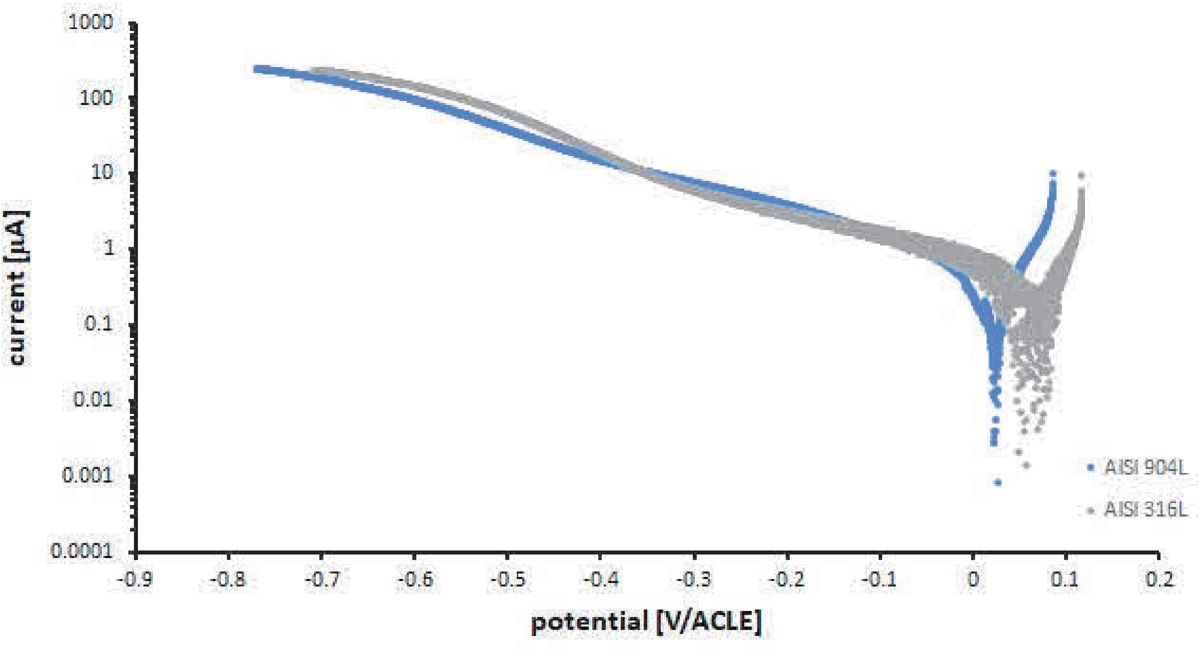

Figure 3 Cathodic part of polarization curves of stainless steel AISI 316L and 904L in model solution at 80 °C

Table 3 Polarization parameters of stainless steels at 80 °C in model solution

Specimen	β_a (V/decade)	β_c (V/decade)	E_{corr} (V/ACLE)	i_{corr} (A m^{-2})	v_{corr} (µm/a)	RP (Ω m^2)
316L	0.187	-0.243	-0.131	0.035	27.2	10.1
904L	0.175	-0.284	-0.228	0.015	11.7	13.2

4. CONCLUSION

In this study, stainless steel AISI 316L and AISI 904L were compared. Stainless steels have been investigated in 1M H_2SO_4 + 1 ppm F^- at 80 °C in simulating an aggressive bipolar plate condition in a PEMFC environment. Both linear sweep voltammetry and potentiodynamic curves measurements indicated that the performance of the steels improved with the increase in the chromium content in the alloy, with AISI 904L being the better candidate for the application as a material for bipolar plates.

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This section includes acknowledgment of people, grant details, funds, etc. Size font is 10 pt, italics, gaps 6 and 0, bold, center align.

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