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Surface conductivity and stability of metallic bipolar plate materials for polymer electrolyte fuel cells

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Abstract

Different types of commercial stainless steels, Ni-based alloys and nitride-coated steels were evaluated as metallic bipolar plate in terms of interfacial contact resistance (ICR) and corrosion resistance in conditions typical of PEFC anode and cathode environments. Results show that stainless steel have a high ICR and undergo corrosion in both anode and cathode. Moreover, although Ni-based alloys showed an ICR comparable with graphite, their behaviour was not satisfactory in corrosive acidic medium. Only nitride-coated stainless steel demonstrated to have low ICR and very good corrosion resistance.

Keywords: Stainless steels; Ni-based alloys; PVD; Contact and corrosion resistances; PEFC

1. Introduction

Polymer electrolyte fuel cells (PEFCs) are devices that convert the chemical energy of a fuel directly into electrical energy and thus are very promising as an energy source thanks to their high power density performance at low temperature (70–90 °C) [1]. Unlike internal combustion engine there is no burning of the fuel and therefore no generation of pollutants. Since a single cell can only give an output voltage around 0.5–0.7 V the cells are stacked together in series, connected by means of bipolar plates.

The bipolar plates are a multifunctional component in PEFC stacks as they collect and conduct the current from cell to cell, they separate the gases, and the flow channels in the plates deliver the reacting gases to the fuel cell electrodes [2]. In a typical fuel cell stack, the bipolar plates comprise over 80% of the mass, and almost all of the volume. In the absence of dedicated cooling plates, the bipolar plates also facilitate heat management. The most widely used bipolar plate material is graphite, which is ideal in terms of corrosion resistance and conductivity [3,4]. Nevertheless, its high cost and the need for machining to form the flow channels limit this material for applications involving high-volume manufacturing. In addition, graphite is brittle and lacks mechanical strength, and therefore the thickness of the plates cannot be reduced. This results in thicker plates with bulkier sizes and more elevated weights. Due to these problems, alternative materials suitable for use in fuel cell technology and able to achieve long lifetime are a key issue in this research field. Several alternatives to the machining of graphite sheets have been investigated including: compression and injection moulding of graphite-filled polymer [5], carbon–carbon composite materials [6] and carbon–polymer composite materials [7]. Metals can also be used to make bipolar plates, and have the advantages of being very good heat and electricity conductors, can be machined easily (e.g. by stamping), are non-porous, and consequently very thin pieces will serve to keep the reactant gases apart. The major disadvantage of metals is that they are prone to corrosion. To avoid this problem, the possible solutions are the use of corrosion resistant materials such as stainless steel (SS). Many works [8–13] have been carried out lately to broaden the application of 304, 316L, 349^{TM}, 446, and 904L stainless steels in chemical solutions in order to overcome the disadvantage of insufficient corrosion resistance in chloride or oxidizing acid solutions. However, results [8–13] are in accordance with the fact that the common stainless steels present an increase of the contact resistance in a low period of time and also undergo a loss of material [14] in the operative conditions of a PEFC. A

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possible alternative for stainless steel bipolar plates can be the use of nickel-based alloys.

Ni-based alloys are widely used in process industry, energy production in nuclear power plants and as filler materials for welds. When compared with Fe-based alloys (e.g. stainless steel), a generally higher degree of resistance against corrosion is observed for these materials. This can be explained partly by the more noble (approximately 0.18 V) corrosion potential of Ni and by the different properties of the oxide films formed on Ni-based alloys and on Fe-based alloys [15]. In a highly oxidizing ambient such as a PEFC stack, it is essential to characterize the effect of different parameters on the behaviour of the protective oxide films. To date, no works have been addressed to the study of Ni-based alloys for use as bipolar plates in PEFCs.

A second approach could be the use of coating processes already used elsewhere [16–21] in order to protect the metal bipolar plates and to lower the contact resistance. Among the surface coating processes, the physical vapor deposition (PVD) method is probably the most versatile of all and it is capable to deposit thin and dense films for corrosion. In brief, it is a vaporization coating processing in which the basic mechanism is an atom by atom transfer of material from the solid phase to the vapor phase and back to the solid phase, gradually building a film on the surface to be coated. Unfortunately, the available information in the literature on the study of surface-modified stainless steel for application in fuel cell bipolar plates is very poor. Moreover, few are the references [22,23] whose results of contact and corrosion resistance can be compared to each other appropriately.

In this work, the interfacial contact resistance (ICR) of three groups of alloyed materials was evaluated and compared with graphite material, namely common stainless steels (304, 310S, 316L and 904L), Ni-based alloys (Hastelloy® C-2000®, G-30®, C-22® and C-276®) and PVD-coated SS304 with six different types of nitride layers.

The best materials of the second and third groups were compared with common stainless steel, in terms of ICR, in oxidizing conditions typical of PEFCs. Finally, the more resistant of the former two samples to oxidizing conditions was also evaluated in anode reducing medium.

Results confirmed that, in general, low-cost stainless steels have high interfacial contact resistances and undergo corrosion in both anode and cathode environments. In contrast, Ni-based alloys showed a lower ICR than that of graphite, but their corrosion resistances seem not to be adequate for use in PEFCs. Finally, the PVD method proved to be very promising since it owns more than 50% ICR reduction and a marked decrease of corrosion rate with respect to the best stainless steel specimens (SS904L).

2. Experimental

2.1. Materials

The austenitic stainless steel specimens SS316L and SS310S were provided by Ulbrich Stainless Steels and Special Metals, Inc. (USA). SS904L was provided by Gaudenzi s.r.l. (Italy) and SS304 was provided by Metinox (Italy). Hastelloy® C-276®, C-22®, G-30® and C-2000B® Ni-based alloys were provided by Haynes International. The typical chemical compositions of the stainless steels investigated in this work are given in Table 1. The specimens were cut into pieces of about 16 cm^2, polished with #600 grit SiC abrasive paper and cleaned with ethanol and distilled water.

Several polished pieces of SS304 were coated by means of PVD with six different nitride layers from Genta Platit (Ferioli & Gianotti S.p.A Groups, Italy). Table 2 presents the thicknesses of the six different specimens. As reference, two commonly used materials for bipolar plates (XM9612 and BMA5 graphites) were purchased from SGL Carbon Group (Germany).

Table 1
Chemical composition (wt.%) of stainless steels and Ni-based alloys by EDX analysis

Alloy/UNS	Cr	Mo	Ni	Mn	W	Co	Cu	Fe	Others
SS304/S30400	17.6	–	7.2	–	–	–	–	75.0	0.2
SS310S–S31050	17.7	–	10.0	–	–	–	–	68.8	3.5
SS316L–S31603	17.0	2.1	8.9	–	–	–	–	71.8	0.2
SS904L–N08904	20.2	4.9	24	1.2	–	–	–	49.5	0.2
C-276®–N10276	14.5	19.6	54.5	–	5.6	0.5	–	4.7	0.6
C-22®–N26022	18.9	17.4	54.1	–	5.7	–	–	3.4	0.5
G-30®–N06030	26.9	7.2	42.5	–	3.3	2.8	0.7	15.7	0.9
C-2000B®/N060200	22.6	20.1	55.0	–	0.8	–	–	0.9	0.6

2.2. Interfacial contact resistance

In order to obtain optimized parameters for cell assembly, the original method of Davies et al. [10] was used following the modifications done by Wang et al. [11] and Lee et al. [19,20] for measurements of ICR between stainless steel and carbon paper. In our setup, two pieces of conductive carbon paper (Toray TGPH090) were sandwiched between the sample and two copper plates (Fig. 1). The contact resistance was obtained by means of a Burster mod. 2318 milli-ohmmeter. The device operates with the principle of the four-wire current–voltage measurement eliminating transition and lead resistances. The potential difference (V) across the cell was measured whilst a fixed electrical current (I) was passed through the arrangement. The current applied was in the range 90–900 mA. The compaction force was gradually increased with the use of an ATS FAAR (Italy) hydraulic press monitored by means of an Unomat mod. MCX pressure controller.

Table 2
PVD-coated SS304 specimens

Coating	Thickness (μm)
A	1–7
B	1–3
C	1–4
D	1–4
E	1–4
F	1–4