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Corrosion behavior of polyphenylene sulfide–carbon black–graphite composites for bipolar plates of polymer electrolyte membrane fuel cells

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A B S T R A C T

The aim of this work was to study the corrosion behavior of polyphenylene sulfide (PPS) – carbon black – graphite composites regarding their application as bipolar plates of polymer electrolyte membrane (PEM) fuel cells. Electrochemical impedance spectroscopy (EIS), potentiostatic and potentiodynamic polarization tests were used to characterize the electrochemical response of the composites in a simulated PEM fuel cell environment. Cross-sectional views of fractured specimens were observed by scanning electron microscopy (SEM). The results showed that the corrosion behavior depends on the carbon black content incorporated into the composite formulation. There was a trend of decreasing the corrosion resistance for higher carbon black contents. This behavior could be explained based on the porosity and electrical conductivity of the composites.

Introduction

The growing interest in renewable energy sources has driven the development of polymer electrolyte membrane (PEM) fuel cells during the last three decades. Bipolar plates have a central role in the evolution of this technology [1]. These components play functions related to the mechanical stability, thermal and electrical management of PEM fuel cells [2]. To properly perform such functions bipolar plates have to meet stringent technical targets based on different materials properties such as electrical conductivity, mechanical strength, corrosion resistance and thermal stability [3].

Traditional materials for manufacturing bipolar plates are graphite, metals or polymer-graphite composites [4]. Each material class has intrinsic advantages and drawbacks which

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must be carefully considered to carry out a successful materials selection of such components [5]. Polymer-graphite composites have spread out as commercial products due to a suitable combination of easy manufacturing, proper electrical conductivity and reasonable mechanical and thermal stabilities at a relatively low weight [6].

Corrosion resistance is a major concern for metallic bipolar plates due to the well-known and undesirable increase of electrical resistance due to the formation of a less conductive oxide film on the surface of the metallic material in typical PEM fuel cell environments [7,8]. Composite bipolar plates, though, are considered to be little affected by corrosion in PEM fuel cells. Thus, the corrosion resistance of polymer-graphite composites is often neglected in the literature. Notwithstanding, there are several reports showing that carbon-based bipolar plates are affected by corrosion in PEM fuel cells. Graphite, carbon black and carbon nanotubes have been shown to participate in corrosion reactions in simulated PEM fuel cell environments [9,10]. Kakati et al. [11] have found that carbon black and carbon fiber additions to phenolic resin-graphite composites increase the chemical instability of the compound, leading to higher corrosion current densities in simulated PEM fuel cell environments. Recently, Park et al. [12] investigated the corrosion of carbon black supports for platinum-based catalysts in PEM fuel cells under start-up/shutdown cycling conditions. They observed that carbon black particles were prone to corrosion and this diminished the cell performance. Studies by Hung et al. [13] and Hsieh et al. [14] showed that carbon nanotubes are electrochemically stable when used as carbon supports for catalysts in PEM fuel cells. In a previous work [15], our group has shown that the corrosion resistance of acrylonitrile-butadiene-styrene-graphite-carbon nanotube composites decreased as the carbon nanotube content increased whereas the electrical conductivity was not significantly affected by the corrosion tests. Carbon black particles are often reported as presenting lower electrochemical stability than carbon nanotubes [16,17]. However, the effect of corrosion tests on the electrical conductivity of polymer-graphite-carbon black composite bipolar plates is not encountered in the literature.

Polyphenylene sulfide (PPS) is a thermoplastic polymer with excellent chemical and thermal stabilities allied with superior mechanical properties [18]. These characteristics have been explored to produce composite bipolar plates. Some reports have shown the suitability of using PPS-based composite bipolar plates with respect to their mechanical and electrical behaviors [19–22]. In spite of the excellent mechanical and electrical performance of PPS-graphite composite bipolar plates, their corrosion behavior has not been reported yet. Moreover, the effect of incorporating carbon black particles into these composites on both the corrosion resistance and electrical conductivity is also unexplored.

This work aims at shedding some light into this scenario. PPS-graphite composites were prepared with different contents of carbon black particles using hot pressure molding. The corrosion behavior of the composites has been evaluated by electrochemical impedance spectroscopy, potentiostatic and potentiodynamic polarization curves. The electrical conductivity of the composites was also determined before and after the corrosion tests. Scanning electron microscopy (SEM) was used to reveal the morphology of the composites.

Experimental details

Powder commercial PPS resin was supplied by Ticona (Fortron 0214). The major conductive filler were synthetic graphite particles supplied by Asbury Carbons. Carbon black (CB) particles were supplied by Cabot Corporation (Vulcan XC 72).

Six different compositions were prepared as shown in Table 1. The components were firstly mixed in a powder blender for 30 min (Turbula T10B). Next, compression molding was used to prepare the composite plates using a hydraulic press. The processing parameters were as follows: temperature of 300 °C and static pressure of 400 kg cm^{-2} applied during 15 min. The samples were obtained in the form of discs with a diameter of 30 mm and 3 mm thick.

The through-plane electrical conductivity of the composites was evaluated according to same procedure described in Ref. [23]. In this experimental setup the specimens were placed between two pieces of carbon paper (Toray TGPH-060), thus simulating the interfacial contact in a fuel cell stack. This sandwich was placed between two gold-plated copper plates. A constant pressure of 140 N cm^{-2} which is a typical value used in fuel cell stacks was applied to clamp this setup. A constant total electrical current of 2 A was applied by a programmable power supply and the voltage drop across the specimen was determined using a digital multimeter. The through-plane resistance of this system depends on various resistances connected in series. These are represented by the resistance of the gold-plated copper electrodes, the resistance of the two pieces of carbon paper, the bulk resistance of the composite material, the contact resistance between the carbon paper and the gold-plated copper electrodes and the contact resistance between the carbon paper and the specimen. In this regard, the measured resistance (R) of the specimen consisted of the resistance of two carbon papers ($2R_{cp}$), the bulk resistance of the specimen (R_{sp}), two interfacial contact resistances between the carbon papers and the specimen ($2R_{cp/sp}$) and two interfacial contact resistances between the carbon papers and the gold-plated electrodes ($2R_{cp/gpe}$). Thus, R can be expressed as shown in Equation (1):

$$R = 2R_{cp} + R_{sp} + 2R_{cp/sp} + 2R_{cp/gpe} \quad (1)$$

The resistances of the carbon paper pieces (R_{cp}) can be considered negligible. The value of $R_{cp/gpe}$ was obtained by a calibration procedure in which one single piece of carbon

Table 1 – Composites prepared in the present work.

Sample	Mass (%)		
	PPS	Synthetic graphite	CB
CB0	15	85	0
CB1	15	84	1
CB2	15	83	2
CB3	15	82	3
CB4	15	81	4
CB5	15	80	5