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Electrically conductive polymer composite coating on aluminum for PEM fuel cells bipolar plate

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ABSTRACT

Aluminum has many advantages for commercial bipolar plate of PEM fuel cell such as light weight, low cost and easy manufacturing. However, it has a low corrosion resistance under a PEM fuel cell operation condition that is a special issue of all metal bipolar plates. In this study, polypropylene composite coated with aluminum bipolar plates were fabricated to improve the corrosion resistance. However, contact resistance of polymer composite coated aluminum bipolar plate is highly increased due to high contact resistance between aluminum substrate and composite layer. Two different types of inter layers were added to improve the contact resistance. Carbon paper attached and carbon black added samples were fabricated between aluminum substrate and composite. Polyamide-imide/carbon black composite adhesive was used for carbon paper attached on the aluminum plate. The contact resistance of carbon paper attached sample was lower than that of carbon black added sample. And, corrosion resistance was tested by potentiodynamic and potentiostatic methods. The composite coated aluminum attached to carbon paper exhibited properties suitable for PEM fuel cells.

1. Introduction

Fuel cells are being examined by many researchers as a new power source to solve the exhaustion of fossil fuel and global warming. Among the fuel cell systems available, the Proton exchange membrane (PEM) fuel cell is expected to replace the internal combustion engine in transportation applications due to its fast start-up and response time, low operating temperature and high power density. In PEM fuel cell systems, bipolar plates are one of the major parts that have functions with an electrical connection between the electrodes, separation of reactant gases and a pathway for residual water in the cell stack [1]. Conventionally, graphite is used as a bipolar plate because of its high electrical conductivity and chemical stability. However, graphite bipolar plates are relatively expensive with high volume that preclude their commercialization. For this reason, other materials to reduce the cost and volume of stacks have been suggested by many researchers. Stainless steel was suggested as a new candidate for a metallic bipolar plate due to the ease of machining, great mechanical properties and good chemical stability [2]. Although it has good mechanical properties, its heavy weight can be a critical drawback in view of transportation applications. Therefore, a low density material is required. Aluminum is considered to be one of the most suitable material for transportation applications with the special qualities of light weight, low density and low cost. In metal bipolar plate systems, the chemical corrosion caused by acid materials from the electrolyte of the cell is another issue. Aluminum has a lower corrosion resistance than stainless steel. Hence, it requires a surface coating to protect it from the corrosive materials. An electrochemical nickel alloy coating has been suggested by several researchers [3,4]. It was reported that a deposited nickel alloy showed a low contact resistance and corrosion current but required annealing at 400 °C to form a dense surface. Joseph et al. [5] developed a conducting polymer coating process that can improve the corrosion resistance remarkably. However, its low conductivity and high contact resistance can degrade the electrical performance of the cell.

In this study, a polypropylene (PP) based conducting composite, which is an inexpensive process that can be applied to mass production, was coated on the aluminum surface to increase the corrosion resistance. The polymer composite coated metal has high contact resistance because the composite has a polymer-rich layer on both sides of the surface [6]. In an effort to decrease the contact resistance, carbon black particles and carbon paper were added to make an interfacial layer between the metal and composite coating layer. The effects of the interfacial layer on the contact resistance and corrosion behavior were examined.

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Nomenclature

ICR	interfacial contact resistance, mΩ cm^2
E_{SCE}	voltage of saturated calomel electrode, V
Log(i)	log-scaled current density, A cm^{-2}
I	current density, A cm^{-2}

2. Experimental details

2.1. Materials and fabrication

Aluminum 6061 alloy was used as the substrate material in this study. A polymer composite consisting of PP (Samsung Total, HJ400, 40 wt%), carbon fiber (Toho Tenax, Fortafil 201, 10 wt%) and carbon black (50 wt%) was fabricated using an internal mixer (Shokai, Bench kneader) for 30 min at 180 °C. An interfacial layer was introduced to reduce the contact resistance between the polymer composite and aluminum substrate. Two different conducting materials were selected, carbon black and carbon paper. Aluminum substrates, 10 mm × 10 mm × 0.2 mm in size, were polished with 1000–2000 grit sandpaper and cleaned in acetone using an ultrasonic cleaner. For the reference sample (Sample 1), the polymer composite was coated on the aluminum surface using a compression molding technique at 160 °C and 60 MPa. For the carbon black added sample (Sample 2), 14 mg of carbon black particles were sprayed onto the aluminum surface and the polymer composites were coated over the resulting surface. For the carbon paper added sample (Sample 3), polyamide-imide (PAI, 60 wt%) and carbon black (40 wt%) composite, which was dissolved in a N-Methylpyrrolidone (NMP) viscous medium, was painted on the each side of cleaned surface to attach the carbon paper to the aluminum substrate effectively. Carbon paper, which has the same area as the aluminum substrate and the same weight as the sprayed carbon black, was attached to the painted surface. After drying in 120 °C hot air, the polymer composite was coated using the same molding technique. Fig. 1 shows a schematic diagram of the structure of each sample. Further conditions for fabricating bipolar plate and testing the single cell performance are introduced in our previous work [7].

2.2. Interfacial contact resistance tests

The Davies method [8] was used to measure the interfacial contact resistance (ICR). The coated aluminum bipolar plate and carbon papers (Toray TFP-H-060), which are used as the gas diffusion layer (GDL) in the PEM fuel cells, were mounted between two copper plates. The resistance of the circuit was measured while a specific current was induced. The ICR was calculated using the technique described in Ref. [9]. In the case of the composite coated metal bipolar plate, the calculated ICR value contained the contact resistance between the top of the surface of a sample and GDL as well as the contact resistance between the surface of a metal and the bottom of a coating layer. In order to evaluate the effect of carbon paper and carbon black particles on the contact resistance, the ICR of each sample was measured as a function of the compacting pressure.

2.3. Corrosion resistance tests

Potentiodynamic and potentiostatic tests were carried out in a 1 M H_2SO_4 + 2 ppm HF solution at 70 °C purged with H_2 and O_2 using a Bio Logic potentiostat VMP3 to determine the corrosion resistance of the bare and coated aluminum bipolar plates. A conventional three electrodes cell system was used. A graphite and saturated calomel electrode (SCE) was used as the counter and reference electrode, respectively. The potentiodynamic polarization curves for coated aluminum were measured over the range, −0.4 V–0.1 V, at a potential scanning rate of 2 mV s^{-1}. In the case of bare aluminum, potentiodynamic curve was measured over the range of −0.1 V–0.1 V with same scanning rate of coated aluminum. The potentiostatic curves were measured for 3 h in −0.1 V and 0.6 V, which correspond to the anode and cathode conditions in PEM fuel cells.

3. Results and discussion

3.1. Micro structures

Fig. 2 shows cross sectional scanning electron microscopy (SEM) images of Samples 1 and 2. At the top side of the cross sections, each sample shows a carbon fiber embedded polypropylene composite. Sample 1 had a simple structure just touching with two materials. It is expected that the nano-size polymer-rich layer may

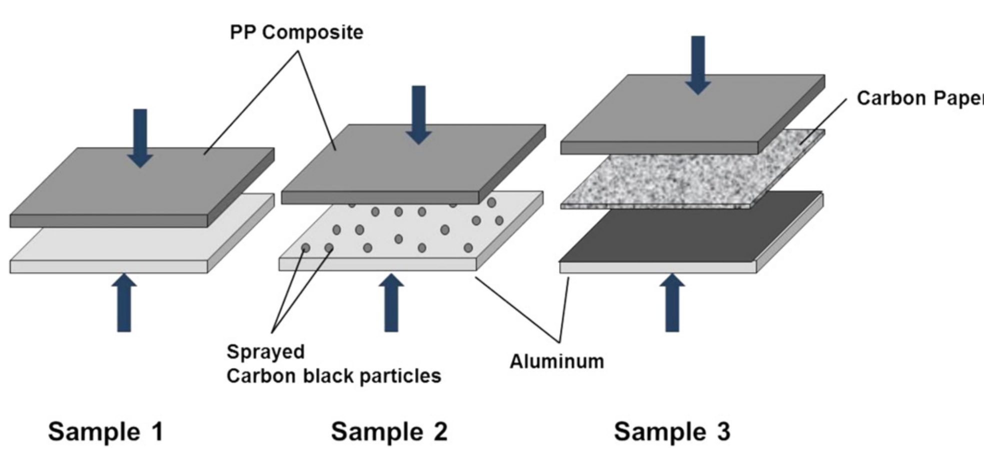

Fig. 1. Structures of the barely coated (Sample 1), carbon black added (Sample 2) and carbon paper added (Sample 3) samples.