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Conductive particles embedded carbon composite bipolar plates for proton exchange membrane fuel cells

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ABSTRACT

Proton exchange membrane (PEM) fuel cell systems are environmentally friendly power sources that have many potential applications. Although carbon fiber composite bipolar plates have high strength and stiffness with good corrosion resistance in an acid environment, they exhibit only a marginal electrical conductivity, which compromises the efficiency of PEM fuel cells.

In this work, electrically conductive particles (graphite powder and carbon black) are sprayed onto carbon–epoxy composite prepregs of a bipolar plate to decrease the electrical resistivity of the bipolar plate. The electrical resistance and mechanical properties are measured using conventional test methods. In addition, a unit cell performance assessment is conducted with the developed carbon composite bipolar plates and compared with that of the conventional bipolar plate.

1. Introduction

Despite the well-established commercial products available for manufacturing PEM fuel cells, there is still on-going work to develop better composites with maximized electrical conductivities [1]. Carbon composite bipolar plates are advantageous over metallic and graphite bipolar plates in terms of corrosion resistance, weight and thickness. Additionally, carbon composite bipolar plates with complex shapes can be produced economically using compression, transfer or injection molding methods, depending on the number of units to be manufactured [1–4]. However, carbon composite bipolar plates have a higher gas permeability and bulk resistance than those of conventional graphite bipolar plates, which compromises the efficiency of a PEM fuel cell [1]. The mechanical strength for stationary applications is completely adequate because a carbon fiber composite has, by at least one order of magnitude, greater strength and modulus than those of graphite plates. In fact, if fuel cells replace internal combustion engines, it might be necessary to only consider vibration or noise problems that are typical of vehicle applications because of the reduced mass [5].

Therefore, the greatest handicap is the lack of electrical conductivity, which is critical in the final application of the device [6]. To increase the electrical conductivity of advanced composite materials, other carbon-based conductive fillers besides conventional graphite can be incorporated into the polymer matrix. These fillers include carbon black (CB), multi-walled and single-walled carbon nanotubes (MWCNT and SWCNT), carbon fibers, expanded graphite and combinations thereof [7–9]. Graphite powder and carbon black are used in various electrochemical applications due to their high purity, electrical and thermal conductivities, specific surface properties and attractive price/performance ratio [10].

However, balancing the electrical conductivity and mechanical strength of polymeric composites is a problem [11]. The conductive network and mechanical strength of a composite depend on the content, morphology, processing and size of the added particles. This extremely complicated behavior is often investigated for specific filler–matrix pairs. However, there is still much to learn to clarify the mechanisms that govern the electrical behavior of carbon-filled bipolar plates in a comprehensive way [1].

In this paper, the relationship between the characteristics of embedded conductive particles and the bulk resistance was investigated to help develop optimized composite bipolar plates for PEM fuel cells. To increase the electrical conductivity, conductive particles (natural graphite powder and carbon black) were embedded into carbon composite bipolar plates by spraying conductive particles onto composite prepregs before stacking, which greatly decreased the electrical resistance. The electrical resistance and mechanical properties were measured using conventional test methods. In addition, the unit cell performance assessment was conducted with the developed carbon composite bipolar plates embedded with conductive particles, and the results were compared with those of the conventional bipolar plate.

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Table 1
Properties of continuous unidirectional carbon fiber prepregs (USN-020 A, SK chemical, Republic of Korea).

Density (kg/m^3)	Thickness after curing (1 ply, mm)	Fiber properties			
		Modulus (GPa)	Strength (GPa)	Fiber volume fraction (%)	Fiber areal weight (g/m^2)
1.48×10^3	0.02	235	4.4	50	22

Table 2
Material properties of conductive particles.

Material		Particle size	Purity (F.C.%)	BET surface area (m^2 g^{-1})
Natural graphite powder	Hyundai Coma, HC 902	2.5 μm	98.5	
Carbon black	Ketjenblack, EC-600JD	34 nm	99.0	1270

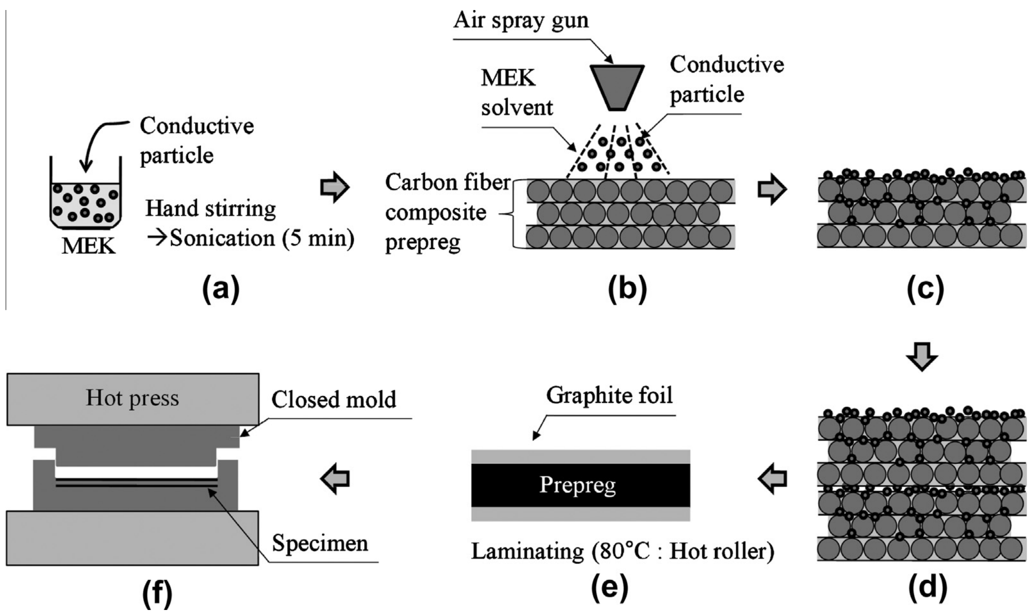

Fig. 1. Fabrication processes of the conductive particles-embedded bipolar plate: (a) preparing the conductive particles mixed in a solvent; (b) spraying the solvent mixture; (c) drying the MEK and precisely measuring the mass; (d) stacking the pregregs; (e) graphite coating process; and (f) compression molding.

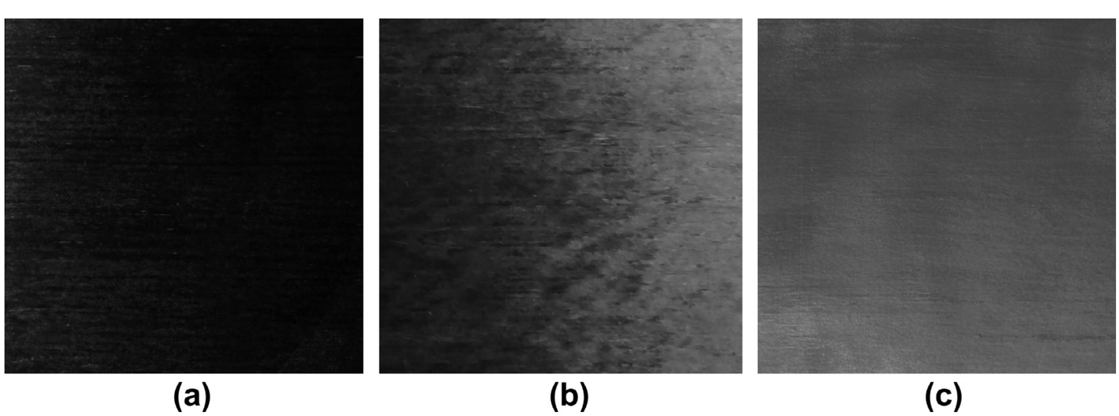

Fig. 2. Conductive particles sprayed on prepregs: (a) neat prepreg; (b) carbon black-sprayed prepreg; and (c) natural graphite powder-sprayed prepreg.

2. Experimental

2.1. Fabrication of bipolar plates embedded with conductive particles

The carbon composite specimens were fabricated with unidirectional, continuous carbon fiber/epoxy prepregs with the thicknesses of 20 μm after curing (USN-020 A, SK Chemical, Republic of Korea); its properties are shown in Table 1. To increase the electrical conductivity, conductive particles were embedded in the bipolar plate via a spraying method. The conductive particles used were natural graphite powder (HC 902, Hyundai Coma Industry Inc., Republic of Korea) and carbon black (Ketjen black 600JD,