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Ultra high speed curing bipolar plates made of carbon fabric/phenolic composite using acid catalyst for proton exchange membrane fuel cell

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ABSTRACT

The proton exchange membrane fuel cell (PEMFC) is composed of bipolar plates, end plates, membrane electrode assemblies (MEAs) and gas diffusion layers (GDLs), from which the bipolar plate is a major component to determine the cost, volume and performance of the PEMFC stack.

In this study, the bipolar plate has been developed using carbon fabric/phenolic composite because phenolic resin has much faster cure reaction than epoxy resin, which enables the carbon/phenolic resin based bipolar plate to be mass-produced. The p-toluene sulfonic acid catalyst is used to accelerate the curing reaction of carbon fabric/phenolic, and the electrical conductivity and tensile strength of the composites are measured with respect to catalyst content because these two characteristics of composite determine the performance of composite bipolar plate.

The experimental results show that the curing time of the carbon fabric/phenolic decreased much as the amount of catalyst is increased. However both the tensile strength and interfacial contact resistance of the composite also decrease as the amount of catalyst is increased because the excess catalyst works as impurities in the composite. Therefore, an optimum content of the catalyst is investigated considering the electrical conductivity with little compromise of mechanical properties.

1. Introduction

A fuel cell efficiently generates electrical power from chemical energy without generating pollutants such as NOx or Sox. It produces water and electricity through the electrochemical reaction of hydrogen and oxygen when they are supplied to the anode and cathode sides, respectively. Among several fuel cell types, the proton exchange membrane fuel cell (PEMFC) is a very promising power source for residential and mobile applications due to its low operating temperature (60–80 °C), high power density and low emissions [1,2]. PEMFC stacks are composed of unit cells (sandwich-type structures formed by bipolar plates, a gas diffusion layer (GDL), and a membrane electrode assembly (MEA) layer) and endplates, as shown in Fig. 1.

The bipolar plates comprise the major part of the PEM fuel cell stack in terms of weight and volume, contributing almost 80% of the total weight and 50% of the total cost [3,4]. They are responsible for functions of vital importance to the long-term operation of these electrochemical devices [5] and are required to satisfy the following functional requirements [6,7]. They provide flow channels for reactant gases as to maintain proper pressure distribution, transmit electrons from anode to its adjacent cathode, support other components of the stack for assembly and transfer the reaction heat from active area to coolant. For those functions, bipolar plates must have high electrical and thermal conductivities, gas impermeability, mechanical strength and corrosion resistance. Graphite is most common material used for bipolar plates because it has good electrical conductivity and excellent corrosion resistance with low density. However, the graphite is little suited to the levels of mass production required for the full scale commercialization because it lacks mechanical strength due to its inherent brittleness and high manufacturing costs for flow channels [8,9]. Several metals are also envisaged as possible bipolar plate materials because they offer good electrical conductivity, excellent gas impermeability and ease of fabrication. However, they are unable to resist corrosion because metallic bipolar plates undergo corrosive processes in the PEMFC environment and require an expensive coating [10–12].

Composite bipolar plates composed of polymeric resins reinforced with short carbon fibers, graphite powder or carbon are an attractive option for PEMFC stack because they offer the advantage of low cost, lower weight and greater ease of manufacture. However, their electrical conductivity and mechanical properties barely meet the requirements of the Department of Energy of the USA (DOE) as shown in Table 1 [13,14].

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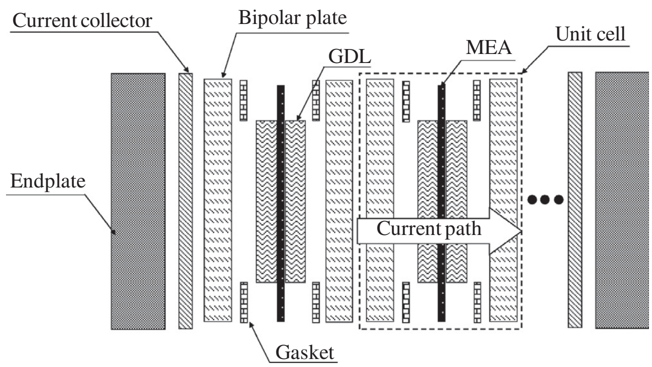

Fig. 1. Schematic diagram of a PEMFC stack.

Table 1
US-DOE target values for composite bipolar plate.

Required properties	US-DOE target values
Low weight	<0.4 kg kW^{-1}
Flexural strength	>25 MPa
Electrical conductivity	>100 S cm^{-1}
Areal specific resistance	<0.03 Ohm cm^2 @ 1.5 MPa
Gas permeability	$<2 \times 10^{-6}$ cm^3 $(s\ cm^2)^{-1}$
Corrosion resistance	<1 μA cm^2

Recently, composite bipolar plates have been developed using continuous carbon fiber to solve the problems mentioned above. The carbon composite is considered as a potential material due to its high mechanical properties, low manufacturing cost and volume [15–18]. However, the long curing time of the resins (~30 min) still remains the biggest obstacle for mass production. Therefore, the curing time and temperature should be reduced to meet the requirement of mass production for commercialization.

In this study, the bipolar plate was developed using plain weave carbon fabric/resole type phenolic composite to increase the productivity of fuel cells and the electrical conductivity. Phenolic resins are inexpensive, have excellent chemical and thermal strength and cure much faster than epoxy resin [19]. The acid catalyst was used to reduce the curing time and curing temperature of the resole type phenolic. The phenolic resin cures in a few minutes at room temperature with acid catalyst. The electrical resistance and tensile strength of the composites were measured with respect to the wt.% of the acid catalyst. Also nanosize carbon black was mixed with phenolic resin and the surface of carbon fabric/phenolic composite bipolar plates was treated with flame to reduce electrical resistance of the bipolar plates.

2. Experimental

2.1. Material and fabrication of composite specimens

The composite specimens were fabricated with a woven-type carbon fiber (CF3327, Hankuk carbon, Korea) in the form of 3 K plain weave with the thickness of 250 μm, a thread count of 0.51 × 0.51 per mm (13 × 13 thread count per inch) and an areal density 205 g m^{-2}. The carbon fabric/phenolic composites were fabricated by impregnating the plain weave carbon fiber with the resole-type phenolic resin (KC-4100B, Kangnam Chemical, Korea) with acid catalyst using the hand lay-up method. Finally, the impregnated laminate was cured by the hot pressing in a closed mold under curing pressure of 10 MPa at 120 °C.

2.2. Curing process monitoring with dielectrometry

The pot life of the phenolic resin was measured by a dielectric sensor. The dielectrometry and dielectric sensors were employed to monitor the resin status in this work because dielectrometry was known to be a promising technique for monitoring the curing process of thermosetting resin matrix composite materials during a production molding operation [20]. The principle of dielectrometry is to monitor the cure state by measuring the dissipation factor, which is the amount of energy loss expended in aligning its dipoles and moving its ions in accordance with the direction of an alternating field [21].

The temperature and dissipation factor of the resin during cure were measured through the cure monitoring circuit as shown in Fig. 2 with respect to the wt.% of the acid catalyst. An interdigital dielectric sensor as shown in Fig. 2(a) and a K-type thermocouple were embedded in the phenolic resin and then the resin was cured in the oven as shown in Fig. 2(b). The dielectric measurements were performed with a commercial LCR meter (U1733C, Agilent, Malaysia) and dielectric sensors (CM102, Lacomtech, Korea).

2.3. Measurement of the electrical resistance of the bipolar plates

The total resistance of the specimens in the through-thickness direction was measured using the experimental set-up shown in Fig. 3(a). A 1.0 A current was applied through the specimens using a current source (ORS-030A, ODA, Korea) and a compaction pressure of 1.5 MPa was applied to the specimens using a material testing machine (INSTRON 4469, Instron, USA). Two copper plates coated with gold were used as electrodes, and the voltage drop was measured using a multi-meter (3457A, Hewlett Packard, USA).

The total electrical resistance of PEMFC stack contains the bulk resistances of the GDLs ($2R_{GDL}$) and the bipolar plate specimens

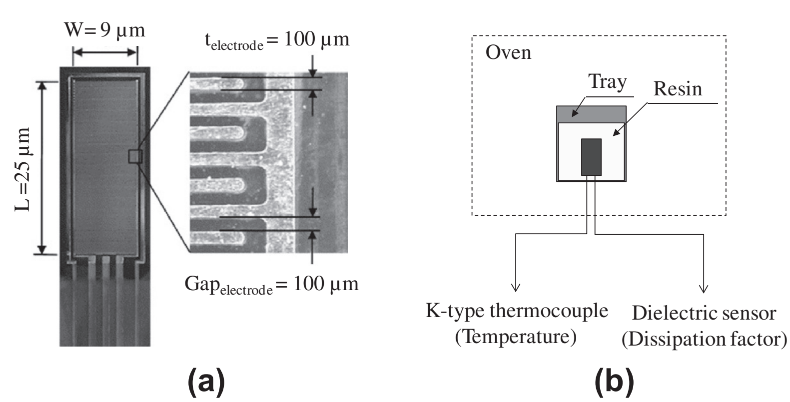

Fig. 2. Dissipation factor and temperature measurement set up for phenolic resin: (a) interdigital dielectric sensor and (b) schematic drawing.