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Method for exposing carbon fibers on composite bipolar plates

Dongyoung Lee [a], Jun Woo Lim [b], Soohyun Nam [a], Ilbeom Choi [c], Dai Gil Lee [a,*]

[a] School of Mechanical Aerospace & Systems Engineering, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea
[b] LANL-CBNU Engineering Institute Korea, Chonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju 561-756, Republic of Korea
[c] Agency for Defense Development, P.O. Box 35, Yuseong-gu, Daejeon 305-600, Republic of Korea

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ABSTRACT

The carbon/epoxy composite bipolar plate is an ideal substitute for the brittle graphite bipolar plate for proton exchange membrane fuel cells (PEMFCs) and vanadium redox flow batteries (VRFBs) because of its high mechanical properties and easy manufacturing. However, due to the resin-rich area that forms on its surface, the carbon/epoxy composite bipolar plate requires an expanded graphite coating to decrease the areal specific resistance (ASR). The expanded graphite coating not only increases the manufacturing costs but also has very low mechanical properties.

In this work, an innovative manufacturing method that exposes carbon fibers on the surface of the carbon/epoxy composite bipolar plate was developed. Soft release films were inserted between the mold and the composite to prevent the formation of a resin-rich area and to expose carbon fibers on the surface of the bipolar plate. The developed method considerably decreased the ASR of the carbon composite bipolar plate without an expanded graphite coating, which satisfied the target established by the Department of Energy (DOE) of United States. The effects of the soft layer on the mechanical and electrical properties of the carbon composite bipolar plate were investigated.

1. Introduction

A proton exchange membrane fuel cell (PEMFC) is an electrochemical energy converter that uses hydrogen and oxygen as fuels to produce electricity with by-products of only water and heat. The primary components of PEMFCs are bipolar plates, end plates, membrane, gas diffusion layers (GDL), and gaskets. The unit cell of the PEMFC stack is composed of GDL-platinum doped membrane-GDL layers sandwiched between bipolar plates as shown in Fig. 1(a). The unit cell of the vanadium redox flow battery (VRFB) stack is composed of carbon felt electrode-membrane-carbon felt electrode sandwiched between bipolar plates as shown in Fig. 1(b).

Among these components, the bipolar plates are multifunctional components with the three main requirements: high electrical conductivity in the through-thickness direction, high mechanical properties, and gas tightness in the through-thickness direction [1]. First, bipolar plates should possess high electrical conductivity because they transmit electrons from the anode to the adjacent cathode. Second, high mechanical properties are required to withstand the high clamping force in the stack assembly. Third, the gas tightness should be secured to prevent mixing of the fuels.

The Department of Energy (DOE) of United States has established target values for each of these requirements, as shown in Table 1. Various materials, such as nonporous graphite, metals, and composites have been proposed to satisfy these requirements. Compared to conventional graphite or metals, carbon/epoxy composite bipolar plates have a high specific strength and high specific stiffness. However, a large areal specific resistance (ASR) due to a high contact resistance with the GDL has been the largest drawback for carbon composite bipolar plate. The high contact resistance is due to the resin-rich area that forms on the surface of the plate, which hinders direct contact between carbon fibers of the bipolar plate and the GDL.

In general, composite bipolar plates are manufactured using a compression molding process, in which the surface roughness of the molds determines the surface roughness of the composite. A polished compression mold treated with a mold release is typically adopted, as shown in Fig. 2(a). When a composite is fabricated using this mold, the surface of the composite is smooth, as shown in Fig. 2(b), because the resin completely fills the gap between the carbon fibers. Many studies have been performed to avoid the high contact resistance resulting from the resin covering the carbon

* Corresponding author.
E-mail address: dglee@kaist.ac.kr (D.G. Lee).
URL: http://scs.kaist.ac.kr (D.G. Lee).

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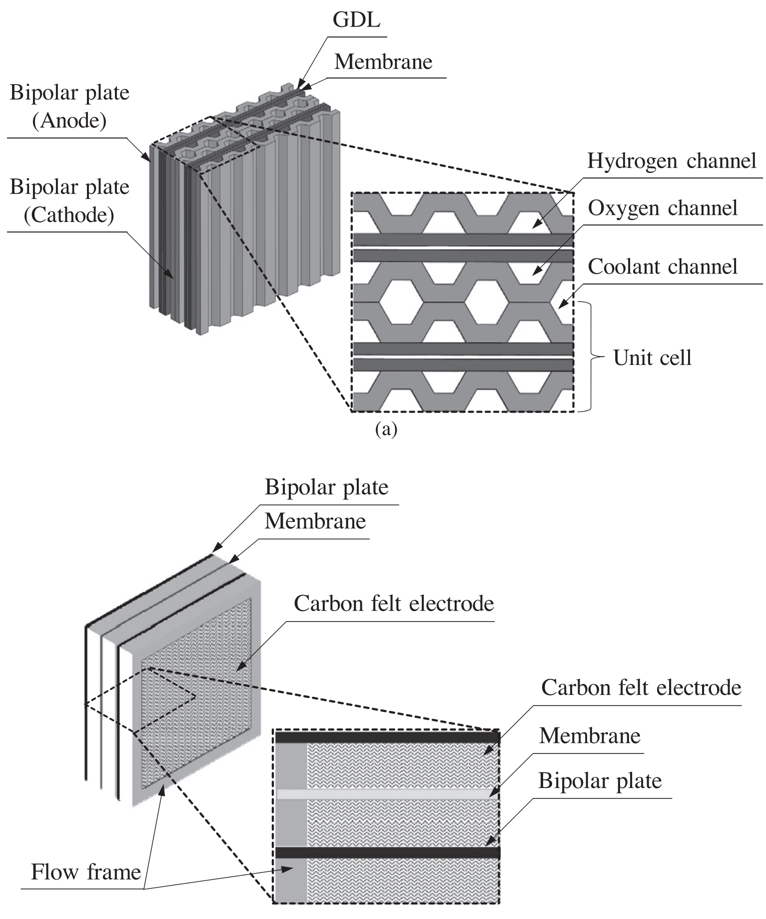

Fig. 1. Schematic diagram of bipolar plates in: (a) PEMFC; (b) VRFB.

fibers, and these studies can be divided into two categories: the surface treatment and the conductive layer coating.

The purpose of surface treatment is to selectively remove the resin while maintaining the carbon fibers as shown in Fig. 2(c). The surface treatment methods include mechanical abrasion [2], microwave treatment [3,4], and plasma treatment [5,6] of the composite. However, these surface treatment methods were not very effective in reducing the ASR.

The conductive layer coating method includes an expanded graphite coating [7–9], as shown in Fig. 2(d). The conductive layer coated on the bipolar plate acts as an electrical bridge between the carbon fibers of the GDL or carbon felt electrode and the composite bipolar plate. Although a conductive layer such as an expanded graphite coating effectively reduced the ASR, expanded graphite is expensive and possesses a very low strength. Moreover, when expanded graphite-coated composite bipolar plates were adopted for the vanadium redox flow battery (VRFB) system, as shown in Fig. 1(b), dimples were generated at the surface during operation as a result of the electrolysis of sulfuric acid which could damage the entire VRFB system [10]. Therefore, for long-term operation of the system, the expanded graphite coating method should be replaced.

In this study, an innovative fabrication method for removing excess resin and exposing bare carbon fibers on the surface of bipolar plates was developed by using a soft release layer. The "soft layer method" employs a thin polymer release film between the compression mold and the composite, as shown in Fig. 3(a). After curing and detaching of the soft layer, the fabricated bipolar plate had carbon fibers exposed on the surface, as shown in Fig. 3(b), because the excess resin was squeezed out during the manufacturing process by the soft release films. The properties of composite bipolar plates produced using the soft layer method were investigated. The electrical properties were investigated by measuring the ASR. The mechanical properties were investigated because the removal of the resin on the surface could deteriorate the mechanical properties of the composite. Tension tests and three-point bending tests were performed to measure the tensile strength and flexural strength, respectively. Finally, the gas permeability of the bipolar plates was measured in the through-thickness direction.

Table 1
DOE target values for composite bipolar plates.

Characteristic	Units	Target value
Flexural strength	MPa	>25
Areal specific resistance	$m\Omega\ cm^2$	<30 at 1.38 MPa
Gas permeability	$cm^3/s\ cm^2$	$<2 \times 10^{-6}$

2. Finite element analysis

2.1. FEA modeling

Finite element analyses (FEA) were performed using a commercial FEA software package (ABAQUS 6.10, SIMULIA, France) to predict the behavior of the soft layer during the compression molding process. The developed 2-D FEA model is shown in Fig. 4(a), which