Composite Structures 140 (2016) 77–83

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Electro-mechanical properties of the carbon fabric composites with fibers exposed on the surface

Dongyoung Lee, Dai Gil Lee *

School of Mechanical Aerospace & Systems Engineering, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea

ARTICLE INFO

Article history:
Available online 4 January 2016

Keywords:
Carbon/epoxy composite
Fuel cell
Bipolar plate
Electro-mechanical property
Soft layer method

ABSTRACT

The carbon/epoxy composite is an ideal substitute for the brittle graphite bipolar plate of the proton exchange membrane fuel cell (PEMFC) because of its high mechanical property and productivity. However, composite bipolar plate suffered from high electrical contact resistance due to the resin-rich area formed on the surface. In order to decrease the contact resistance, "soft layer method", which could expose bare carbon fibers on the composite surface, was developed. The soft layer method significantly improved the electrical properties of the unidirectional continuous carbon fiber/epoxy composite at the expense of slight degradation of the mechanical properties.

In this work, the soft layer method was improved further to develop the carbon fabric/epoxy composite bipolar plate for the PEMFC. Compared to the conventional composite bipolar plates, the developed composite bipolar plates showed superior electrical properties as well as significant increase in the mechanical properties and gas tightness.

1. Introduction

Bipolar plate is a multifunctional key component for proton exchange membrane fuel cell (PEMFC). Among various functional requirements, three crucial requirements of the bipolar plates are high electrical conductivity in the through-thickness direction, high mechanical property, and low gas permeability in the through-thickness direction [1]. First, bipolar plates should have high electrical conductivity to minimize the ohmic loss. Second, high mechanical property is required to withstand high compaction pressure in the stack assembly. Third, the gas permeability should be very low to prevent the mixing of the fuels. Various materials, such as graphite, metals, and composites have been proposed to satisfy these requirements. Compared to the conventional graphite or metals, carbon/epoxy composite bipolar plates have high specific strength and high specific stiffness [2,3].

However, low electrical conductivity and large areal specific resistance (ASR) due to the high contact resistance with the gas diffusion layer (GDL) has been the largest drawback of the carbon/epoxy composite bipolar plate. The high contact resistance is due to the resin-rich area that is formed on the surface of the bipolar plate during compression molding process. The resin-rich area prevents direct contact between carbon fibers of the bipolar plate and the GDL, which results in high ASR.

Many studies have focused on reducing the ASR, which can be divided into two categories: surface treatment and conductive layer coating. The purpose of the surface treatment is to selectively remove the resin while maintaining carbon fibers. The surface treatment methods include mechanical abrasion [4], plasma treatment [5]. However, these surface treatment methods failed to satisfy the ASR target value established by Department of Energy (DOE) of the United States. Conductive layer coating, such as expanded graphite coating, succeeded to satisfy the DOE target [6]. However, the expanded graphite is expensive and possesses a very low strength. Moreover, it has durability problem due to the dimple generation under acidic environment.

Very recently, "soft layer method," an innovative fabrication method of removing resin-rich area and exposing bare carbon fibers on the surface of the composite bipolar plates was developed using a soft release film [7]. At the expense of slight decrease in the mechanical property, the soft layer method significantly reduced the ASR which satisfied the DOE target by a great margin without any surface treatment or conductive layer coating. However, only unidirectional continuous carbon fiber composite was investigated in this study, whereas, more rigidly woven fabric-type composites are more advantageous for the manufacture of bipolar plates with larger size, higher performance, and higher productivity.

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

http://dx.doi.org/10.1016/j.compstruct.2015.12.066
0263-8223/

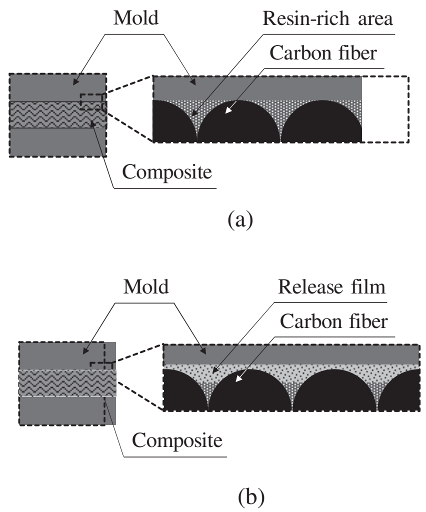

Fig. 1. Manufacturing methods: (a) conventional compression molding; (b) soft layer method.

In this study, the soft layer method was further improved for the manufacture of fabric-type carbon composite bipolar plate. The composite bipolar plates composed of 1k and 3k carbon fabrics were fabricated using an improved soft layer method which employed thicker soft layers and purging process. The electrical property, mechanical property, and gas permeability of the developed bipolar plates were measured and the effect of bundle size, soft layer thickness, and purging process was investigated.

2. Fabric vs. unidirectional continuous fiber

Unidirectional continuous carbon fiber composites are generally fabricated using prepregs because impregnation of the resin into the fibers and handling are not easy. However, fabric-type composites can be easily fabricated by impregnating the resin into the fabric due to relatively rigid woven structure of the fabric. Therefore, the fabric-type composites are advantageous than unidirectional continuous fiber composites for fabricating a large size bipolar plate with special resin systems. To fabricate a composite for high temperature application, a fabric-type fibers can be easily impregnated with high temperature epoxy or other matrix materials, which are not easy to obtain in prepreg form.

Fig. 1 shows the compression molding methods of the conventional and the developed soft layer method [7], and Fig. 2 shows the surface morphologies of the unidirectional continuous carbon fiber composite and fabric-type composite manufactured with the soft layer method. The unidirectional continuous carbon fiber composite has flat surface with only 3.5 µm roughness, which is the radius of the carbon fiber, as shown in Fig. 2(a). Therefore, the surface resin of the composite could be removed effectively even with a small deformation of the soft layer. However, the fabric-type composite has relatively large peak–valley height difference due to woven fiber bundle structures, as shown in Fig. 2 (b). Therefore, the deformation of the soft layer should be larger to remove the resin at the valley and to expose fibers on the surface.

3. Fabrication of the specimen

The composite bipolar plate specimens were fabricated with 1k plain weave carbon fabric/epoxy prepreg (WSN 1k, SK chemicals, Korea) and 3k plain weave carbon fabric/epoxy prepreg (WSN 3k, SK chemicals, Korea) whose properties are shown in Table 1. The 1k fabric has 1000 carbon fibers in one bundle, and the 3k fabric has 3000 carbon fibers in one bundle. Due to the larger bundle size, the 3k fabric has a larger peak-valley structure compared to the 1k fabric. A 25 µm-thick fluorinated ethylene propylene (FEP) film (A4000V, Airtech, United States), which is widely used as a release film, was adopted as a soft layer. The thickness of the soft layer was controlled by varying the number of release films. The soft layer thickness was varied from 25 µm to 100 µm and 25 µm to 150 µm at intervals of 25 µm for the 1k fabric composite and the 3k fabric composite, respectively. The prepregs were stacked with

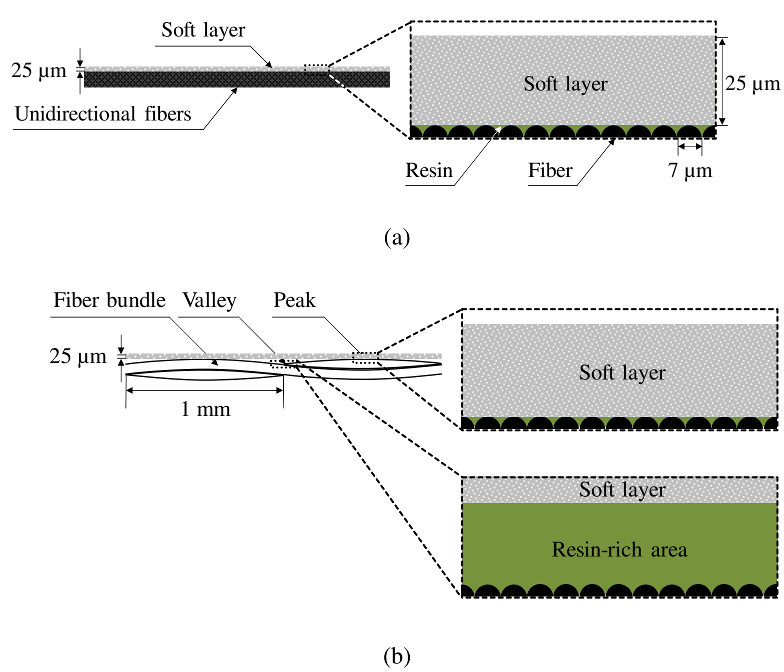

Fig. 2. Surface morphologies of the unidirectional and fabric composites manufactured with the soft layer method: (a) unidirectional continuous fiber; (b) 1k fabric.