INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 36 (2011) 9916–9925

Available at www.sciencedirect.com

ScienceDirect

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

Effects of gas diffusion layer structure on the open circuit voltage and hydrogen crossover of polymer electrolyte membrane fuel cells

Kyung Don Baik [a], *Sung Il Kim* [a], *Bo Ki Hong* [b], *Kookil Han* [b], *Min Soo Kim* [a,*]

[a] School of Mechanical and Aerospace Engineering, Seoul National University, Seoul 151-744, Republic of korea
[b] Fuel Cell Vehicle Team 1, Eco-Technology Center, Hyundai-Kia Motors, Yongin-Si, Gyeonggi-Do 446-912, Republic of korea

ARTICLE INFO

Article history:
Received 16 February 2011
Received in revised form
27 April 2011
Accepted 13 May 2011
Available online 15 June 2011

Keywords:
Gas diffusion layer
Polymer electrolyte membrane fuel cell
Membrane puncturing
Open circuit voltage
Hydrogen crossover

ABSTRACT

The clamping pressure of polymer electrolyte membrane fuel cells for vehicle applications should be typically high enough to minimize contact resistance. However, an excessive compression pressure may cause a durability problem. In this study, the effects of gas diffusion layer (GDL) structure on the open circuit voltage (OCV) and hydrogen crossover have been closely examined. Results show that the performances of fuel cells with GDL-1 (a carbon fiber felt substrate with MPL having rough surface) and GDL-3 (a carbon fiber paper substrate with MPL having smooth surface) are higher than that with GDL-2 (a carbon fiber felt substrate with MPL having smooth surface) under low clamping torque conditions, whereas when clamping torque is high, the GDL-1 sample shows the largest decrease in cell performance. Hydrogen crossover for all GDL samples increases with the increase of clamping torque, especially the degree of increase of GDL-1 is much greater than that of the other two GDL samples. The OCV reduction of GDL-1 is much greater than that of GDL-2 and GDL-3. It is concluded that the GDL-3 is better than the other two GDLs in terms of fuel cell durability, because the GDL-3 shows the minimum OCV reduction.

1. Introduction

The growing concerns on environmental issues and CO_2 emission regulations have constantly demanded cleaner and more energy-efficient vehicles. To meet such demands, the polymer electrolyte membrane fuel cell (PEMFC) has been suggested to provide a clean power source for transportation applications in the future. In PEMFCs, one of the most important components is a gas diffusion layer (GDL). The GDL performs the essential functions such as passage for reactant gases and electrons transports, heat and water removal, mechanical support to the membrane electrode assembly (MEA), and protection of the catalyst layer from corrosion or erosion caused by flows or other factors. The GDL usually consists of a micro-porous layer (MPL) and a macro-porous substrate or backing [1–3]. Generally the MPL, which is composed of carbon powder and hydrophobic agent such as polytetrafluoroethylene (PTFE), is coated on the macro-porous substrate of GDL in order to lower the electrical contact resistance between the GDL and the catalyst layer in MEA. The macro-porous substrate consists of hydrophobic agent and carbon fiber supports such as felt, paper, or cloth [2], and plays important roles in removing the excessive product water and providing a path for electrons to flow between catalyst layer

* *Corresponding author*. Tel.: +82 2 880 8362; fax: +82 2 883 0179.
E-mail address: minskim@snu.ac.kr (M.S. Kim).
0360-3199/$ – see front matter
doi:10.1016/j.ijhydene.2011.05.088

Nomenclature

A	active area [cm^2]
C	hydrogen concentration [ppm]
F	nitrogen flow rate [$L\ min^{-1}$]
m	molar flow rate [$mol\ s^{-1}\ cm^{-2}$]
n	molar weight [$g\ mol^{-1}$]

Greek letter

ρ	density [$g\ L^{-1}$]

Subscript

C.O	cathode outlet
H_2	hydrogen gas

and bipolar plate [1–3]. As described in the literature [2], the carbon fibers in the felt substrate appear more entangled and three-dimensional structure, while those in both paper and cloth substrates exhibit more straight structure.

During the assembling process of fuel cell stack, the compression or clamping pressure of PEMFCs for vehicle applications is typically high enough to minimize contact resistance among the cell components such as MEA, GDL and bipolar plate. Lin et al. [4] examined how compression pressure affects the fuel cell performance under various operating conditions. They claimed that applying the optimum compression on the GDLs is important because the increase of the compression pressure reduces the pore volume of GDLs, which decreases the fuel cell performances. Radhakrishnan et al. [5] investigated the change in the overall structure and properties of the GDL when subjected to such cyclic compression and Chang et al. [6] experimentally studied the effect of clamping pressure on the performance of a PEMFC. They examined the effect of the clamping pressure on the electro-physical properties of a carbon fiber paper GDL such as porosity and gas permeability. Likewise, most researches were focused on the relationship between physical characterizations of GDLs and fuel cell performances under a variety of clamping pressure conditions.

A few experimental studies have been done to understand the membrane degradation when compression pressure increased. Mittelsteadt et al. [7] investigated membrane puncturing due to the diffusion media (carbon fiber paper materials) penetration into the membrane under various membrane thickness and relative humidity (RH) cycling conditions. They focused on the relationship between membrane properties and membrane puncturing and also measured the specific resistances to identify membrane puncturing. According to this study, carbon fiber penetration makes several micro-holes in the MEA surface when clamping pressure is too high. Those micro-holes are the cause of the membrane degradation because hydrogen and oxygen can easily penetrate into the membrane through the micro-holes. Thus membrane degradation process is accelerated in these spots. Lai et al. [8] conducted an accelerated stress test to compare the shorting performance of various material sets using a current distribution measurement technique to monitor the local shorting behavior. Likewise, several experimental researches about the membrane puncturing under various clamping pressures have been conducted. To the best of our knowledge, however, hydrogen crossover due to the membrane puncturing as a function of the clamping pressure has not been reported in literatures.

In this study, membrane puncturing due to the carbon fiber penetration into the membrane has been investigated, and hydrogen crossover and open circuit voltage (OCV) for three types of GDLs were measured. The performances of cells with different types of GDLs were also measured under various clamping torque conditions. Lastly, morphological images of the GDLs and the catalyst layer in MEA have been analyzed by scanning electron microscopy (SEM) in connection with hydrogen crossover to elucidate the membrane puncturing process.

2. Experimental method

2.1. *Gas diffusion layers*

Three types of commercial GDL were used in this study. The GDLs used in this study are listed in Table 1. The GDL-1 has a macro-porous substrate of carbon fiber felt with MPL-1 coating type of a rough surface, the GDL-2 has a carbon fiber felt substrate with MPL-2 coating type of a smooth surface, and the GDL-3 has a carbon fiber paper substrate with MPL-2. The results of GDL-1 and GDL-2 are compared to investigate the effect of MPL type on the membrane puncturing, and the results of GDL-2 and GDL-3 are compared to explain the effect of carbon fiber structure in macro-porous substrate on the membrane puncturing. The thickness of all the GDLs was measured with at least 20 measurements per each GDL using a Mitutoyo thickness gauge (Mitutoyo Co., Tokyo, Japan) and the values of average and standard deviation were listed in Table 1.

2.2. *Single cell and experimental apparatus*

In this study, a single cell with an active area of 25 cm^2 was used. As listed in Table 2, the single fuel cell is composed of end plates, graphite bipolar plates with a 5-serpentine channel for both anode and cathode flow fields, GDLs, gaskets and an MEA. A commercial MEA was used for all the experiments. Teflon gaskets were also used to prevent the gas leakage. A torque wrench (CDI Torque Product, USA) was used

Table 1 – Characteristics of GDLs used in this study.

Code name	Macro-porous substrate type	Micro-porous layer coating type	Thickness (μm)
GDL-1	Carbon fiber felt	MPL-1 (rough surface)	426 ± 10
GDL-2	Carbon fiber felt	MPL-2 (smooth surface)	423 ± 5
GDL-3	Carbon fiber paper	MPL-2 (smooth surface)	365 ± 6