Available online at www.sciencedirect.com
ScienceDirect
Journal of Power Sources 171 (2007) 26–36
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Inhomogeneous compression of PEMFC gas diffusion layer Part I. Experimental

Iwao Nitta[a,*], Tero Hottinen[b], Olli Himanen[a], Mikko Mikkola[a]

[a] *Helsinki University of Technology, Laboratory of Advanced Energy Systems, P.O. Box 2200, 02015 HUT, Finland*
[b] *Wärtsilä Corporation, Tekniikantie 14, 02150 Espoo, Finland*

Received 4 September 2006; received in revised form 10 November 2006; accepted 14 November 2006
Available online 8 December 2006

Abstract

This paper presents a study on the effect of inhomogeneous compression of gas diffusion layer (GDL) caused by the channel/rib structure of flow-field plate. The experimentally evaluated properties are GDL intrusion into the channel, gas permeability, in-plane and through-plane bulk electric conductivities, and contact resistances at interfaces as a function of compressed thickness of GDL. It was found that the GDL is compressed very little under the channel whereas GDL under the rib is compressed to gasket thickness. The compression of GDL reduces gas permeability and contact resistance, and improves bulk conductivity. Hence, the inhomogeneous compression of GDL may lead into significant local variation of mass and charge transport properties in the GDL. These effects have been ignored in most of the published modeling studies. This contribution, part I, covers the experimental setup and measurement results, and a model which takes the inhomogeneous compression of GDL into account is presented in part II.

Keywords: PEMFC; Gas diffusion layer; Inhomogeneous compression; Contact resistance; Gas permeability; Electrical conductivity

1. Introduction

Proton exchange membrane (PEM) fuel cells are electrochemical devices that convert the chemical energy of reactants directly into electrical energy. This technology enables high efficiency and energy density compared to conventional internal combustion engines, thereby making the technology attractive for automotive, portable, and stationary applications. Furthermore, the only exhaust from PEM fuel cells is water, which makes them favorable from the environmental point of view.

PEM fuel cell consists of bipolar plates with channels machined on either side for reactant distribution over the electrode surface, membrane electrode assembly (MEA) where the electro-chemical reactions and proton transport takes place, and porous gas diffusion layers (GDL) sandwiching the MEA. Among the components of PEM fuel cell, much research effort has been put on catalysts, membranes and bipolar plates.

Until recently, less attention has been paid to GDL even though it plays an important role in fuel cell operation. The main functions of GDL are to provide a passage for reactant access and product water removal, to conduct electricity and heat between adjacent components, and to provide mechanical support for the MEA. These functions impose requirements on the electrical and mechanical properties of GDLs, i.e. high gas permeability and suitable water management properties, electrical and thermal conductivity, and chemical and physical durability. Typically, GDLs are made of highly porous carbon-fiber based paper or cloth.

The properties of GDL and interfaces between the GDL and the electrode and flow field plate are strongly dependent on compression pressure. Generally speaking, increasing compression improves electrical and thermal conductivity, and impedes reactant transport and water removal. A flowchart of the effects of increasing compression is presented in Fig. 1.

Pressure onto the GDL is exerted by the flow field plates, which usually feature flow channels for reactant distribution. The rib/channel-structure creates an inhomogeneous compression distribution, because the GDL under ribs is compressed to gasket thickness while GDL under the channels remains mostly uncompressed and intrudes into the channel, see Fig. 2.

DOI of original article:10.1016/j.jpowsour.2006.10.076.
* Corresponding author. Tel.: +358 9 451 3158; fax: +358 9 451 3195.
E-mail address: iwao.nitta@hut.fi (I. Nitta).

0378-7753/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jpowsour.2006.11.018

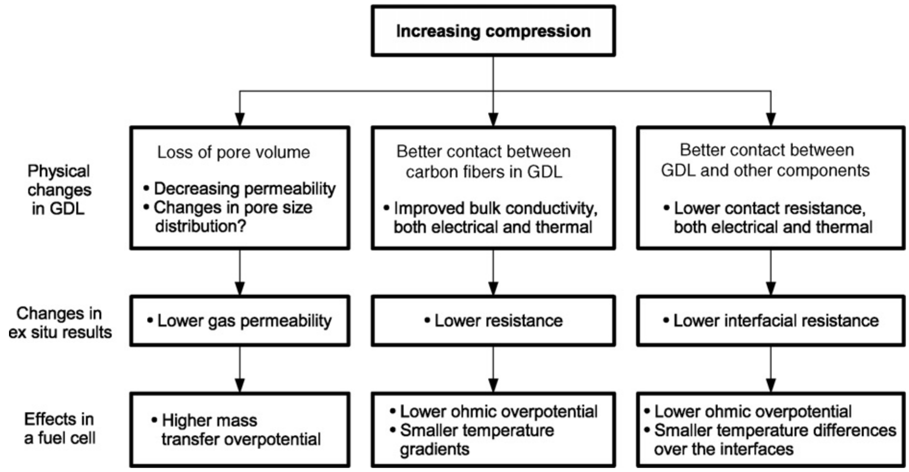

Fig. 1. The effects of increasing compression of GDL.

Inhomogeneous compression distribution leads into spatial variation of GDL and interface properties. Fluid permeability is lower in the GDL under the ribs due to loss of porosity, which increases mass transport overpotential in those areas compared to areas under the channel. Similarly, electrical and thermal bulk conductivities are improved and contact resistances at the interfaces between the GDL and electrode and flow field plate are smaller than those under the channel.

These effects exist in all fuel cells with normal flow field plates but cannot be measured directly due to small scale of the phenomena. Thus, the only available option is to characterize the GDLs *ex situ* and model the effect. Furthermore, most of the published fuel cell models do not account for the inhomogeneous compression of the GDL and its effects. Usually GDL thickness, porosity, contact resistances and conductivities are assumed constant over the cell area. There may be a significant discrepancy between the modeled results and practical situation due to these assumptions. Only few studies, such as by Sun et al. [1] and Zhou et al. [2], were found by authors, in which the effect of inhomogeneous compression of GDL is taken into account. However, Sun et al. did not account for the contact resistance, and Zhou et al. ignored the effect of compression on the bulk conductivity of GDL.

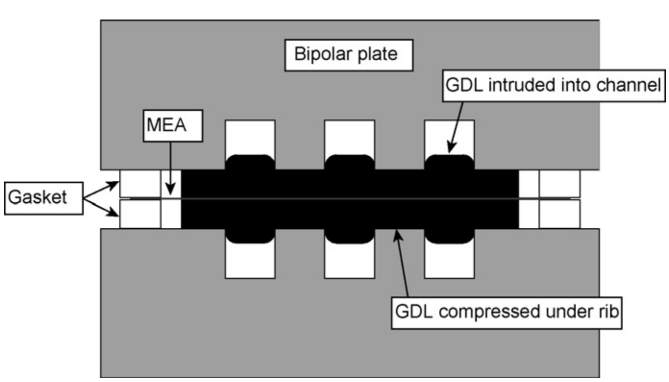

Fig. 2. Schematic illustration of GDL deformation under compression. The GDL partially intrudes into the channels and the parts under the ribs are more compressed.

Effects of compression and GDL properties on fuel cell performance have been studied by several groups, e.g. Lee et al. [3], Ge et al. [4], and Ihonen et al. [5]. The results show that the compression force and physical properties of GDL must be considered together and there is an optimum compression pressure and compressed thickness for each GDL which trades off the competing demands of mass, charge and heat transport within the GDL.

GDL parameters, such as permeability, both electric and thermal conductivity and contact resistance between components have been investigated, e.g. Dohle et al. [6], Williams et al. [7], Feser et al. [8], Ihonen et al. [9], Mishra et al. [10], Wang and Turner [11], Vie and Kjelstrup [12] and Khandelwal and Mench [13]. However, in contact resistance studies [9–11], the effect of compression on bulk conductivity was ignored. Furthermore, Ihonen et al. [9] and Natarajan and Nguyen [14] found that fuel cell operating parameters or experimental operating conditions also affected the contact resistance. Relating to compression, it has been observed that excessive compression damages the carbon fibers in GDL materials, e.g. Wilde et al. [15], Escribano et al. [16] and Matsuura et al. [17].

Some of the actual GDL properties have been included in published fuel cell models. Chu et al. [18] considered the non-uniform porosity due to presence of water in GDL. Berning and Djilali [19], Natarajan and Nguyen [20], Inoue et al. [21], and Jang et al. [22] modeled the mass and charge transport with various operating parameters and studied the impact of geometric parameters of flow field and material properties of GDL such as porosity and thickness. Pharoah [23] applied anisotropic gas permeability into their models, and Meng and Wang [24] and Pharoah et al. [25] modeled the effect of anisotropic electrical conductivity and observed large variations between isotropic and anisotropic cases. However, the authors did not find any models that took into account the spatial variations in permeability, and electrical and thermal conductivity due to inhomogeneous compression. This may cause significant errors in modeled results, e.g. in the prediction of current density distribution, and therefore it is worth studying how the compression pressure affects charge and species transport.