INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 40 (2015) 5958–5965

Available online at www.sciencedirect.com

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Mechanical characterization and analytical modeling of gas diffusion layers under cyclic compression

P.A. Gigos [a,b,c], Y. Faydi [b,c], Y. Meyer [b,c,*]

[a] Ecole Polytechnique, Universite Paris-Saclay, 91128 Palaiseau, France
[b] IRTES-M3M, UTBM, 90010 Belfort Cedex, France
[c] FCellSys, Rue Thierry Mieg, 90000 Belfort, France

ARTICLE INFO

Article history:
Received 10 November 2014
Received in revised form
16 February 2015
Accepted 28 February 2015
Available online 1 April 2015

Keywords:
Gas diffusion layer
Cyclic compression
Irreversible deformation
Analytical model
Nonlinear behavior

ABSTRACT

Gas Diffusion Layers (GDLs) play a major role in the performances of Proton Exchange Membrane Fuel Cells (PEMFC). However, their mechanical properties are poorly studied in the literature. In fact, most papers treating an overall PEMFC assume a linear GDL behavior. Articles focusing on GDLs sometimes consider a nonlinear behavior or cyclic compressions above 6 MPa, but no paper considers these two constraints at the same time. Yet it has been proven that a GDL in a running fuel cell undergoes local pressures higher than 10 MPa and has a nonlinear response. The purpose of the present study is to investigate the mechanical behavior of three industrial GDLs under those extreme coupled conditions. In this paper, the results of the experimental investigation are presented. Then, an analytical model is developed. A nonlinear behavior is obtained and compared to the experimental data. A good agreement between the experimental data and the analytical model is obtained for each GDL reference.

Introduction

The Proton Exchange Membrane Fuel Cell (PEMFC) is an electrical power generator. Electricity is produced in dozens of elementary cells connected in series into a stack. An elementary cell is described in Fig. 1. Hydrogen and oxygen react in the membrane electrode assembly (MEA) to form water, heat and electricity. The reactant gases are supplied through channels perforated in bipolar plates and, then, cross through the gas diffusion layers and react on the catalyst layer. This layer is coated on the membrane surfaces. On the anode-side, hydrogen molecules are reduced into protons by freeing electrons. The protons cross through the membrane and react on the cathode-side with oxygen by producing water that is eliminated in specific channels.

The Gas Diffusion Layers (GDLs) play a major role in a running fuel cell. First, they must allow a homogeneous distribution of gas from the channels to the membrane. Then, they have to evacuate the water created during the chemical reaction [1]. In a running fuel cell, the gas diffusion layers are exposed to an inhomogeneous mechanical pressure that can be locally higher than 10 MPa [2]. This is due to the thermal expansion and mainly to the humidity. Indeed, the membrane

* Corresponding author. IRTES-M3M, UTBM, 90010 Belfort Cedex, France.
E-mail address: yann.meyer@utbm.fr (Y. Meyer).
http://dx.doi.org/10.1016/j.ijhydene.2015.02.136

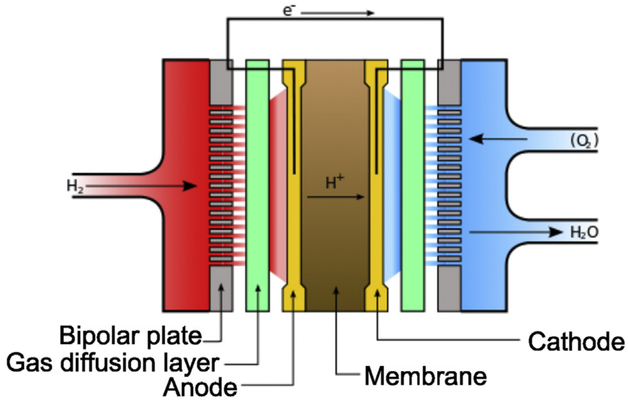

Fig. 1 – PEMFC elementary cell (from wikipedia).

can increase its volume of 50% of its initial dry volume. Of course, the humidity ratio depends on the operating point on the polarization curve of the PEM fuel cell and on the operating start-and-stop cycle. That is why the study of mechanical compression cycles is essential. The GDL behavior under mechanical compression has been proven to be nonlinear, with an irreversible deformation [3]. However, in existing experiments and models, the GDL nonlinear behavior has not been conjointly studied under high pressure (higher than 10 MPa) and multiple loading/unloading cycles. In their experiments, Matsuura et al. [4] apply a pressure of 20 MPa but consider only the first mechanical compression. Garcia-Salaberri et al. [5] have modeled the GDL compression modulus by using piecewise polynomial fits found in the literature, but they also consider only the first compression.

Therefore, the present paper goes further by using an experimental approach to investigate the effects of high mechanical pressures combined with cyclic compressions. Then a nonlinear analytical model is developed from an existing linear model. Finally, the model developed is calibrated and compared to experimental data.

Experimental approach

Material and methods

Description of the samples

A GDL is a thin layer made of carbon fibers which can be either randomly arranged (carbon paper), or woven (carbon cloth). GDLs can be coated with PTFE to improve water management. A MicroPorous Layer (MPL) can also be added as a coating. Three industrial GDLs provided by the company SGL CARBON are analyzed in this paper. Their PTFE rate grows from 0 to 5 wt% PTFE and an MPL has been added on one of them. Their detailed characteristics are presented in Table 1.

Sample holder

Since the mechanical measurement apparatus is not able to deliver a force higher than 65 N, a sample holder with a very small contact surface (5.3 mm^2) was manufactured and used. Consequently, a 12 MPa pressure can be reached. On the surface, the contact is ensured by three cylindrical studs

Table 1 – Characteristics of the GDLs studied.

GDL ref.	Sample thickness (m)	PTFE addition (wt%)	MPL addition
SGL 24 AA	190±30	0	No
SGL 24 BA	190±30	5	No
SGL 24 BC	235±30	5	Yes

located at the vertices of an equilateral triangle with a 1 cm edge to obtain a good mechanical stability. The parallelism of the sample holder is managed by means of a ball device ensuring homogeneous pressure distribution. A Computer-Aided Design picture of the sample holder that we have developed is depicted in Fig. 2.

Mechanical measurements

Measurements are performed with a Dynamic Mechanical Analysis (DMA) test machine (Metravib VA2000). Basically, as illustrated in Fig. 3, this machine consists of a displacement sensor, a temperature control system, a load sensor, a drive motor in order to apply the stress conditions, a drive shaft and a guidance system [6]. With the coupled software (Dynatest), a cyclical quasi-static load is applied on the GDL sample. During each experiment, ten compression cycles are applied to a virgin GDL with a mechanical compression up to 12.6 MPa. The excitation signal applied to the samples is optimized with respect to the experiment duration and the maximal pressure amplitude. This is possible because we did not observe any creep effect on the GDLs tested and because the mechanical behavior of the GDLs is stabilized after five loading and unloading cycles, that is to say there is no mechanical behavior modification after five cycles. In Fig. 4, the applied force is drawn for the first 8 cycles.

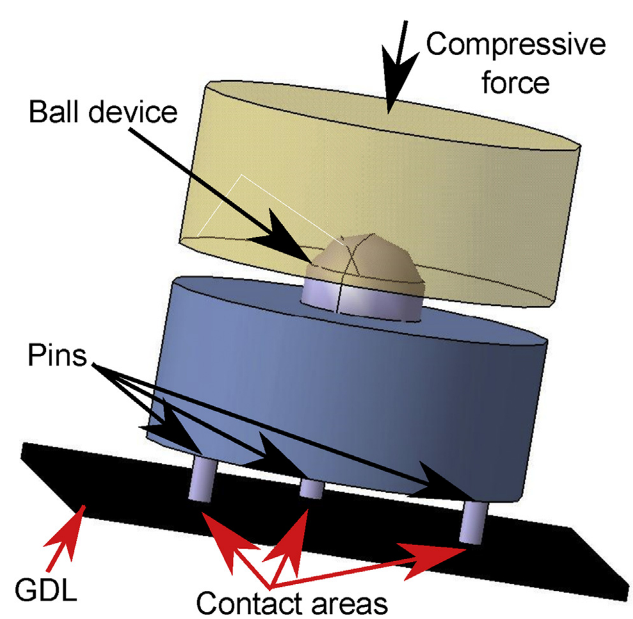

Fig. 2 – Sample holder with its contact surface made of three studs.