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1. Introduction

PEMFCs (Proton Exchange Membrane Fuel Cells) can be used as clean electrical generators in transportation, portable, and stationary applications. A PEMFC is made of a membrane coated with two similar Catalyst Layers (CLs) at each membrane side (Membrane Electrode Assembly - MEA). The MEA is sandwiched between two Gas Diffusion Layers (GDLs). These elements provide the flow of reactants to the catalytic sites and allow the removal of the product water. Each GDL is typically composed of a sheet of carbon paper in which the carbon fibers are partially coated with polytetra-fluoroethylene – PTFE. Gases rapidly diffuse through the pores of the GDL. These pores are kept open by the hydrophobic PTFE, which prevents excessive water buildup. In many cases, the GDL is coated with a thin layer of high-surface-area carbon mixed with PTFE, called the micro-porous layer (MPL). The MPL gives the possibility to manage retention of water to ensure electrolyte conductivity and gas flow inside the GDL. All these components are maintained between two Bipolar Plates (BPPs) making a cell. The cell is subject to different mechanical stresses and the GDL is the most sensitive element because of its high porosity (up to 80%). Internal stresses are mainly due to the amount of water contained in the membrane making it swelling or shrinking. A part of the internal stresses is also due to the thermal expansion of the different components. In the other hand, external constraints are primarily due to the clamping pressure applied from the stack terminal plates, usually with fasteners (bolts and nuts). The FC is also subject to frequency excitations especially in transportation applications.

In this paper, we review the different studies aiming at clarifying the relationship between the mechanical constraints supported by the GDL and the different performances of the cell (electrical, mechanical, and thermal performances, including phenomena linked with water management, structural changes, and durability).

2. Cell performance under mechanical constraints

2.1 Mechanical performance of the cell

The influence of the mechanical pressures on the GDL mechanical behaviour has been studied by several authors. N. Ul Hassan et al. [1] found the best pressure torque for their specific cell to obtain the best performance (i.e. minimum contact resistance between GDL and BPP). This pressure torque gave the most uniform pressure distribution. P.A. Gigos et al. [2] found that the mechanical behaviour of the GDL was stabilised after 5 cycles of compression due to the fibre rearrangement. They also developed a model to describe the stress-strain relation taking into account the porosity changes, the residual strain, and a calibration coefficient with the experimental values. G M. Dominguez Almaraz et al. [3] investigated the fatigue endurance of carbon paper sheet used for GDLs.

2.2 Electrical performance

Studies relating electrical performance to mechanical conditions are more numerous. The simulation of C. Chien et al. [4] highlights a linear relationship between compression ratio and bolt pre-loading stress, a decrease of porosity and an increase of conductivity under compression. M. Hamour et al. [5] measured the in-plane conductivity of the GDL and BPP set (stainless steel foam BPP) using the Van Der Paw method. They found that conductivity increases under compression up to a maximum value. They also found that the GDL-BPP conductivity tends to the BPP conductivity under pressure, and that the number of samples does not change much the results. M. Zhiani et al. [6] found that ultrasonic bath used to manufacture the MPL is one of the best methods to have a good performance of GDL under compression. D. Singdeo et al. [7] found that the GDL-BPP contact resistance decreases with pressure and also with temperature. S. El Oualid et al [8] found that GDL-BPP contact resistance decreases non-linearly with compression, and that PTFE added to the GDL increases the compression resistance. A MPL added to the GDL decreases the contact resistance.

2.3 Thermal performance

Thermal performance has also been explored regarding the mechanical excitation. H. Sadeghifar et al. [9] found that the thermal GDL-BPP contact resistance increases with both MPL and PTFE, and the out-of-flateness of the BPP. Load cycling reduces the total thermal BPP-GDL resistance considerably. This reduction is more pronounced for GDLs with lower PTFE rate. Y. Faydi et al. [10] found that the compression modulus depends on static preloads;

the compression modules increases linearly with temperature until 280°C, then it decreases linearly.

2.4 Water management, structural changes, and durability

Controlling the moisture rate in a PEMFC is an important issue since this rate is directly proportional to the membrane conductivity. Having an excess of water causes flooding, while a lack of humidity will dry the membrane. A.H. Mahmoudi et al. [11] found that after 35% compression, major damage was found on the cathode side (current limitation and flooding). The mechanical excitations also affect the GDL structure. S. Prass et al. [12] found that the gaps which were formed between the CL and the MPL depend on the roughness and irregularities of their surfaces, that they decrease with compression, and that a good CL-MPL contact can be obtained as long as the roughnesses of the surfaces are similar. The PEMFC durability is a major issue that needs to be investigated in order to have a cost-effective product. H. Ishikawa et al. [13] improved the durability of their cell from 300 to 30000 cycles by reducing the mechanical strain of the membrane by 50% in its center and by 80% in the edge, all of that by adding a sub-gasket and selecting a soft GDL to reduce the shrinking-swelling of the membrane and stress concentrations.

3. Overview of the results obtained in the field

Mechanical compression has a major effect on the cell performance. It may reduce the electrical and thermal contact resistance as long as the material is not damaged. The compression does not have much effect on the bulk properties. Of course, the best global performance was not found for the maximal mechanical load because compression also reduces the GDL porosity, which increases mass transport resistance and thus lowers the reaction rate. It was found that adding PTFE increases the compression resistance but also the contact resistance. Adding MPLs helps having a better compression resistance and allows an even smaller contact resistance. Compression also affects the water management in the cell; the most affected FC section is the cathode because of the higher water accumulation. The compression helps obtaining a better structural rearrangement of the GDL-BPP contact as long as cracks are not induced. Mastering the stress concentrations on the GDL-BPP interface by adding sub-gaskets helps increasing the cell lifetime.

4. Discussion, future research issues and trends

Making cost effective FC components can only be achieved through a deeper understanding of the complex multi-physical phenomena that relate the mechanical stresses with the overall cell performances. The best way to predict exactly what happens within the cell is to combine all the concerned scientific disciplines and the related tests (possibly through in-situ tests to better match with the real FC conditions). This is obviously a hard challenge, but combining two or three physical aspects and properties measured in the same experiment can be the right approach for future research. Very few studies have been conducted by combining several aspects.

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