Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

X-ray computed tomography reconstruction and analysis of polymer electrolyte membrane fuel cell porous transport layers

J.P. James [b,1], H.-W. Choi [a,1], J.G. Pharoah [a,b,*]

[a] Queen's-RMC Fuel Cell Research Centre, 945 Princess St., 2nd floor, Kingston, ON K7L 5L9, Canada
[b] Mechanical and Materials Engineering, Queen's University, Kingston, ON K7L 3N6, Canada

ARTICLE INFO

Article history:
Received 21 May 2012
Received in revised form
16 August 2012
Accepted 17 August 2012
Available online 27 September 2012

Keywords:
Polymer electrolyte membrane fuel cell
X-ray computed tomography
Porous transport layer
Effective property
Non-homogeneous compression

ABSTRACT

A commercially available porous transport layer (SGL carbon group Sigracet® GDL 30BA), is investigated using X-ray computed tomography reconstruction. A novel aspect of this study is an investigation of the effects of non-homogeneous compression of the GDL 30BA sample including effective transport properties. Non-homogeneous compression is typical in polymer electrolyte fuel cells as the flow field plates consist of a series of lands and channels which apply an uneven loading to the porous transport layers. The X-ray computed tomography technique provides input data for the computer reconstruction procedures integrating image post-processing and iso-surface reconstruction. The resulting tomographic and surface reconstruction is converted into the computational volume/grid for microstructural and computational fluid dynamics (CFD) analysis. The heterogeneous compression effects on effective geometric and transport properties are investigated for various compression levels and effective transport properties are compared to theoretical studies such as Bruggeman [1] and Tomadakis and Sotirchos [2]. The effects of non-homogeneous compression are significant, with the transport properties differing by a factor of about 2 between the land and the channel regions. It is found that the effective transport properties are significantly lower than predicted by commonly used relations, with the lowest values representing only 15% of the predictions from the Bruggeman relation.

1. Introduction

The porous transport layer (PTL) is an integral part of the polymer electrolyte membrane fuel cell (PEMFC) system. It is responsible for transporting the reactants hydrogen (H_2) and oxygen (O_2) from the bipolar plates to the catalyst layer as well as for effectively removing the products during PEMFC operation. The material must also efficiently conduct electrons from the anode to the cathode while dissipating the heat of the reaction away from the catalyst layer [3]. Much consideration is involved in attempting to optimize the performance of a material with so many functions especially when some of these functions are inversely proportional to each other while the system is under compression. For these functions to be

* Corresponding author. Queen's-RMC Fuel Cell Research Centre, 945 Princess St., 2nd floor, Kingston, ON K7L 5L9, Canada. Tel.: +1 613 533 6579; fax: +1 613 533 6489.
E-mail addresses: choihw@queensu.ca (H.-W. Choi), pharoah@me.queensu.ca (J.G. Pharoah).

[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.ijhydene.2012.08.077

carried out, the PTL must have a functional pore system that facilitates fluid transport as well as good contact with the catalyst layer to facilitate heat dissipation and electron transport. Properties that are essential for the layers function are water-surface contact-angle, porosity, gas diffusivity, thermal and electrical conductivity and structural integrity [3].

PTLs also feature additional treatments to the carbon fibre matrix which have been found to improve water management. PTLs with added polytetrafluoroethylene (PTFE) have shown to exhibit improved hydrophobic properties which are beneficial in preventing flooding and increasing cell performance [4]. These treatments also add structural integrity to the fibre binder matrix. In light of these benefits, the PTFE content must also be optimized for the carbon matrix it is coating. If too much is added, the optimal pore diameter may be compromised resulting in a reduction in performance. When the PTFE content is optimized, the gas transport through the layer is increased through limiting the saturation level of water [5]. The PTFE loaded PTL, that is the focus of this study, is SGL carbon group Sigracet® GDL 30BA [6,7].

In order to properly understand and optimize the transport phenomena through these porous materials, it is necessary to study the microstructure characteristics of the material to understand its influence on the transport properties. Until recently the main techniques in determining structural data of the PTL have been through the use of scanning electron microscopy (SEM) or manual experimentation. The SEM is useful in obtaining surface structural data but fails to reveal features below the surface. Data from manual experimentation are also very useful but fail to provide localized information at the micro level. A relatively new method for obtaining structural data from the PTL involves the use of non-destructive X-ray computed tomography, also know as computed tomography (CT).

Micro CT is uniquely positioned as a valuable tool for imaging the PTL for a number of reasons. In recent years, this technology has evolved to the point where the cone beam source is able to produce sub-micron resolution. Apparatus sizes vary from simple desktop systems to the more involved lab setups. Micro CT machines are relatively affordable by grant assisted university research groups which makes them more accessible to the average researcher than other high-resolution scanning systems. The polychromatic nature of the tube source on CT has some drawbacks with respect to sample penetration which can lead to the creation of artifacts as well as geometry representation errors during reconstruction [8]. With up-to-date processing algorithms, the impact of anomalies such as beam hardening (X-ray beam attenuation gradually changing with the changes in thickness of the material being imaged which can result in a false representation of the material) and other scanning artifacts can be greatly reduced. Synchrotron tomography on the other hand uses nearly parallel X-rays of a monochromatic nature with a higher photon flux [8]. This reduces the occurrence of artifacts and increases contrast and the overall quality of the obtained images. The major drawback of Synchrotron tomography is the size and cost to run such a facility which reduces its availability to the researcher. Another analysis technique is dual-beam focused ion beam–scanning electron microscopy (FIB-SEM) wherein the material is destroyed through a systematic layer stripping procedure during the imaging acquisition. FIB-SEM is not a suitable tomographic procedure for this study as we require the material to be under compression during scanning. Micro CT has been increasingly used in investigating the PTL using a variety of procedures [9–12].

A novel aspect of this study is the investigation of the effects of non-homogeneous compression of the PTL on effective transport properties. To date, the majority of literature considers uniform compression [13–15]. However, the uniform compression condition is not found under normal operational conditions within the PEMFC. Flow field plates consist of a series of lands and channels that allow for good contact while also allowing for the introduction of reactant gas through the flow channels. The plate geometry applies uneven loading to the PTL which is expected to have an effect on the transport through the material. The areas of transition between the channel and the land are of particular interest for this reason. These repeating patterns may have an effect on transport on a local level. This study will focus on the reconstruction of this region to further study the effects of non-homogeneous compression.

This study uses an Xradia MicroXCT-400 tomography system [16] in conjunction with open-source image processing and computational fluid dynamics (CFD) technique to conduct effective geometric and transport properties analysis of the PTL under realistic loading conditions. In this paper, the X-ray computed tomography technique provides data for the computer reconstruction procedures integrating image post-processing and iso-surface reconstruction. The resulting tomographic and surface reconstruction is converted into the computational volume/grid for CFD analysis. Affects of the heterogeneous compression on effective geometric and transport properties are investigated for various compression levels. Furthermore, the effective gas diffusivity results of the PTL sample are compared to effective medium theory (Bruggeman [1]) and to percolation theory (Tomadakis and Sotirchos [2]), as well as to experimental results available in literature. This work also demonstrates the usefulness of open-source software in the analysis of the effective transport properties of PTLs, which to the author's knowledge has not been reported in literature.

This article is organized as follows. The X-ray computed tomography reconstruction technique, integrating both the X-ray computed tomography and computer reconstruction, is introduced in Sections 2 and 3. Section 2 describes the X-ray computed tomography method including test apparatus, image acquisition procedure, and image post-processing. Section 3 presents the computer reconstruction procedure including surface triangulation, computational domain and mesh generation and effective transport property calculation. Section 4 reports the results and discussion of the proposed model. A summary of general conclusions is given in Section 5.

2. X-ray computed tomography

2.1. *Test apparatus*

Micro CT is an imaging technique that creates three dimensional image volumes where the internal structures of the