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Effect of nonuniformity of the contact pressure distribution on the electrical contact resistance in proton exchange membrane fuel cells

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ABSTRACT

Electrical contact resistance (ECR) is one of the most important factors affecting the ohmic loss in proton exchange membrane (PEM) fuel cells. Dominated by the contact pressure at the interface of two neighboring components, the ECR can be reduced by increasing the clamping force applied on fuel cell stack. However, too large a clamping force will result in excessive resistance to the transport of reactants in the gas diffusion layer (GDL) and even damage to the fuel cell components. Therefore, for a given clamping force, the minimum ECR is expected by making the pressure distribution as uniform as possible. This paper investigates two questions: (a) how to evaluate the distribution of non-uniform pressure based on the ECR, and (b) in what situation will a uniform pressure distribution reduce the ECR obviously, i.e., the sensitivity of the contact resistance to the pressure distribution.

1. Introduction

Owing to the decrease of fossil fuel resources coupled with the increased risk of global warming, fuel cells have been recognized as an alternative power generation technique in numerous applications in the future. Among the various types of fuel cells, proton exchange membrane (PEM) fuel cell is considered as one of the most promising fuel cells, because of its advantages such as low operating temperature, short response time, high efficiency, convenient fuel supply, and so on [1,2].

Ohmic loss is one of the major power losses in PEM fuel cells. The ohmic resistance in a PEM fuel cell usually results from the ionic resistance of the electrolyte membrane and the electronic resistances of the catalyst layer (CL), gas diffusion layer (GDL), bipolar plate (BP), and the interfaces between neighboring two parts. Generally, the most significant ohmic loss comes from the electrolyte membrane in PEM fuel cell with graphite BP. However, for metallic BP and graphite composite BP, which are now widely used to replace the graphite BP, electrical contact resistance (ECR), the resistance to current flow through a closed pair of contacts, may be comparable with the resistance of electrolyte membrane in contributing to the total power loss [3–5]. Therefore, the ECR has received more and more attention in the fuel cell stack design.

In the assembly process of a fuel cell stack, a sufficient contact pressure at the interface between neighboring components should be provided, since the ECR will be dramatically reduced with the increasing interface contact pressure. However, too large a clamping force will result in an excessive resistance to the transport of reactants in the GDL and even in

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the flow channels due to the deformation of the GDL. Therefore, for a given clamping force, how to obtain the minimum ECR is a very important target in fuel cell stack design. In our previous work, it was proposed that the minimum ECR can be obtained when the contact pressure reaches a uniform distribution [4]. In the design of the end plate, a uniform pressure distribution is also expected to reduce the ECR [6]. Nevertheless, due to the geometric features of the BP and the fuel cell stack, it is nearly impossible to obtain a perfectly uniform pressure distribution at the inner interfaces [7]. The pressure distribution at the interface is influenced by the irregular geometrical shape of BP, manufacturing error of all parts in the fuel cell stack, connecting method of end plates, and *etc*. In addition, the regions nearby the bolt connecting locations always have a more significant compression deformation than the other regions. This inhomogeneous compression deformation will induce a significant non-uniform distribution of the contact pressure at the GDL/BP interfaces.

The pursuit of uniform pressure distribution is a tough task in the fuel cell stack design because the pressure distribution is inherently non-uniform due to the bending deformation of the end plates. In fact, even if the end plates are perfectly rigid, the contact pressure distribution is still non-uniform due to either the dimensional error [8] or the assembly error [9]. One of our questions is whether the uniform pressure distribution has such important role as we have always assumed in reducing the ECR. In other words, is the contact resistance sensitive to the pressure distribution? To the best of our knowledge, there is no theoretical analysis previously on the effect of the contact pressure distribution on the performance of PEM fuel cell stack. An evaluation method of non-uniform pressure distribution based on the ECR is needed to assess what a pressure distribution is acceptable.

In this paper, an empirical formula is first introduced to describe the relationship between the contact pressure and the ECR of the GDL/BP interface. Then an evaluation method is proposed for the sensitivity analysis of ECR. Finally, the contact resistances corresponding several typical pressure distributions are analyzed.

2. Electrical contact resistivity models

A mathematical model of electrical contact resistivity (ECR per unit area) is needed to calculate the total ECR of a fuel cell. Although several microstructure based models have been proposed for understanding the contact resistivity between BP and GDL [10,11], an effective empirical equation for depicting the relationship between the contact pressure and ECR is still expected to simplify the calculation of total ECR of GDL/BP interfaces in a fuel cell.

In order to calculate the ECR in PEM fuel cells, the present paper adopts a power function model for determining the relationship between contact resistivity and contact pressure:

$$\rho = a \cdot (P)^b \tag{1}$$

where, P is the contact pressure, a and b are the fitting parameters based on experimental data. This power function model has been widely used to express the relationship between the electrical contact resistivity and the contact pressure in the related researches. In order to check whether the power function model is appropriate to describe the contact resistivity at the interface between GDL and BP, several fitting results of the available experimental data in the available literatures are shown in Table 1. It is found that the contact electrical resistivity at GDL/BP interface can be well depicted by Eq. (1). Therefore, the power function model, adopted as the fundamental model, is used to calculate the relationship between the contact pressure and ECR in this paper.

3. Contact pressure distributions

The ECR is dominated by the pressure distribution at contact interfaces in the PEM fuel cell stack. In order to analyze the effect of pressure distribution on the ECR, we will discuss several typical pressure distributions in a single fuel cell stack in the following.

The non-uniform pressure distribution is generally caused by either the assembly method or assembly error, or sometimes both of them. The effect of assembly method on the pressure distribution has been widely investigated both experimentally and numerically [6,17–19]. In the present work, finite element method (FEM) is employed to simulate the pressure distribution in a single fuel cell stack. The analysis model of a quarter of a single PEM fuel cell stack, as shown in Fig. 1, is divided into 4268 of 8-node plane-strain elements. The contact elements are created at all the interfaces between neighboring parts of PEM fuel cell. Since the thickness of CL is very small compared with the thickness of GDL and electrolyte membrane, it is negligible in the pressure distribution analysis. At the bottom of the model, i.e., the mid-plane of PEM, the symmetric boundary condition is employed. The dimensions and mechanical properties of the components in simulation model are listed in Table 2. The cross section size of the flow channel is 1 mm × 1 mm, and the width of the land is 1 mm. The average contact pressure on the interfaces between GDL and the land of BPP is about 0.45 MPa.

The FEM analysis results are shown in Fig. 2. The normalized contact pressure is defined as the contact pressure, P, divided by the average contact pressure, P_0. It is easy to find the deviation of the contact pressure from the uniform pressure distribution. In Fig. 2, the contact pressure of the corner nodes is neglected in the curve fitting calculation due to the

Table 1 – Power function fitting results of the contact electrical resistivity.

Contact interfaces	Fitting results	Average error	Refs.
GDL(10BA CP)/BP(Graphite)	$\rho = 3.23P^{-0.484}$	4.7%	[12]
GDL(10BB CP)/BP(Graphite)	$\rho = 3.61P^{-0.699}$	4.29%	[12]
GDL(10BB CP)/BP(Graphite)	$\rho = 18.4P^{-1.08}$	5.13%	[13]
GDL(CP)/BP (Carbon composite)	$\rho = 36.9P^{-0.148}$	2.78%	[14]
GDL/BP (316L Bright annealed)	$\rho = 220P^{-1.01}$	0.26%	[15]
GDL(Toray CP)/BP(316L)	$\rho = 222P^{-1.05}$	4.03%	[16]